MONOCULTURE IN AGRICULTURE: EXTENT, CAUSES, AND PROBLEMS--

Report of the Task Force on Spatial Heterogeneity in Agricultural Landscapes and Enterprises

UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

The Task Force on Spatial Heterogeneity in Agricultural Landscapes and Enterprises was established at the direction of Dr. Ned Bayley, then, Director of Science and Education, United States Department of Agriculture. Its purposes were (1) to review the costs and benefits of monocultural systems, (2) to identify potential alternatives to those monocultural systems that appear to be especially susceptible to increased disease, pest, and pollution costs, and (3) to recommend research studies to evaluate the merit of the alternatives.

Development of a satisfactory concept of monoculture was prerequisite to the studies made by the Task Force. There was little hard information available relating to the extent of monoculture in U.S. agriculture. In this report we have assessed the extent of monoculture and the geographic location of intensive monoculture. We believe this is the first time such an assessment has been made. Forestry was not included in the scope of this study although many interrelationships exist. Present cropping patterns have resulted from a combination of forces. Most important are the independent decisions made by many individual farmers on the basis of economic return to the enterprise. These decisions have taken into account such factors as Government farm programs, comparative biological efficiencies of various crops, and levels of technology available for production and handling of various crops.

Because American farmers make decisions mostly on the basis of economic return, viable alternatives or modifications to monoculture must provide equal or greater economic incentive to individual farmers either through the marketplace or through various societal programs that substitute for the marketplace.

The Task Force assessed possible alternatives and modifications to monoculture within such constraints as maintenance of economically viable agriculture and adequate food and fiber supplies at reasonable costs to the public. Recommendations concerning pertinent areas of research were made. One principal objective of this report is to stimulate important research related to spatial heterogeneity in agriculture.

Members of the Task Force represented a variety of geographical areas, a varied professional background, and outstanding expertise in many areas of agriculturally related biology, ecology, systems analysis, and economics. This resulted in a vigorous exchange of ideas and of information supporting these ideas. A full consensus on content of the report could not be attained. A minority report is included as an appendix to provide for expression of some ideas and for presentation of data that was intensely supported by one member but with which the rest of the Task Force did not agree. Disagreement existed partly with respect to substance but principally because most of the ideas and data presented in the minority report extended beyond the scope of the responsibilities of the Task Force.

Author or authors followed by year of publication in parentheses in the text refer to the reference in the Literature Cited at the end of each chapter.

Views expressed by the Task Force and reported here are not necessarily those of the U.S. Department of Agriculture.

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TASK FORCE PARTICIPANTS

Dr. H. J. Hodgson, Chairman of Task Force
Principal Agronomist
Cooperative State Research Service
U.S. Department of Agriculture
Washington, D.C. 20250

Dr. K. J. Frey
Distinguished Professor of Plant Breeding
Agronomy Department
Iowa State University
Ames, Iowa 50010

Dr. F. Glenn Goff
Ecological Science Division
Oak Ridge National Laboratory
Oak Ridge, Tenn. 37830

Dr. D. W. Goodall
Co-Director, US/IBP Desert Biome
Range Science Department
Utah State University
Logan, Utah

Dr. A. A. Hanson
Acting Area Director
Agricultural Research Center
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Md. 20705

Dr. D. F. McAlister
Assistant Director
Agricultural Experiment Station
University of Arizona
Tucson, Ariz. 85721

Dr. Robert Otte
Natural Resource Economics Division
Economic Research Service
U.S. Department of Agriculture
Washington, D.C. 20250

Dr. J. B. Peterson
Laboratory for Application of Remote Sensing
1220 Potter Drive
West Lafayette, Ind.

Dr. Michael Perelman
Department of Economics
Chico State College
Chico, Calif. 95926

Dr. H. J. Reitz
Director, Agricultural Research and Education Center
University of Florida
Lake Alfred, Fla. 33850

Dr. V. M. Stern
Department of Entomology
University of California
Riverside, Calif.

Dr. Earl Swanson
Department of Agricultural Economics
University of Illinois
Urbana, Ill. 61801

Dr. Fred Tschirley
Science and Education Staff
U.S. Department of Agriculture
Washington, D.C. 20250

Dr. B. G. Tweedy
Department of Plant Pathology
University of Missouri
Columbia, Mo. 65201

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SUMMARY OF FINDINGS AND RECOMMENDATIONS

American agriculture has undergone marked transition in the 20th century in response to strong economic forces generated both within and outside of agriculture. This transition has culminated in today's large scale, highly mechanized agriculture that is typified by large inputs of capital, energy, machinery, fertilizer, pesticides and other manufactured products. Modern U.S. agriculture is doing a magnificant job of providing an abundant supply of high quality products for consumers in this country and for a significant number of consumers in other countries.

Agriculture has experienced considerable reduction in spatial heterogeneity, or conversely, an increase in monoculture. Monoculture is defined as "the culture of a crop species in an area in such concentration as to occupy a dominant portion of the production of that area." The use of the word *species* is important. Planting wheat in a field is included in the definition of monoculture; the same field containing native grasses or trees would not, because of the many species of plants which usually would be present. Monoculture also has two dimensions–spatial and temporal. Large scale monoculture has been questioned from ecological standpoints.

Quantification of the extent of monoculture is very difficult with present information. However, data indicate marked shifts in cropping patterns with apparent concentration of certain crops in some areas. Only 12 percent of our counties have over half their area in harvested cropland. It is in these counties that monoculture may be extensive and troublesome. Over 40 percent of our counties had less than 10 percent of their area in harvested crops. There has been a slight tendency for cropland to concentrate in fewer counties during recent years. However, even among counties with a high proportion of land area in harvested crops, considerable range exists in the number of different crops present and the evenness of their distribution.

Most of the direct forces influencing the trend to monoculture have economic roots. Biological superiority of a given crop, optimization of a set of cultural practices for that crop, concentration of managerial expertise, economics of scale, mechanization, delivery of production inputs, and processing facility availability all exert economic forces in the direction of monoculture. Concentration of research on particular commodities increases production technology and profitability for those commodities and contributes to monoculture. Government farm programs also may be economic forces influencing the trend toward monoculture.

Because of these forces monoculture is characteristic of much of the intensified production of food, feed, and fiber in the United States. The development of monoculture enabled farmers to employ high levels of technology and managerial ability. In so doing, they have provided a continually increasing volume of high-quality food, feed, and fiber to the American public at relatively low cost. The continued low overall cost of food and fiber, despite increasing product demand, is a direct benefit to society from the use of monoculture. For the most part net income has risen more slowly in the farm sector than in the nonfarm sector of our economy. Actually, decreased production costs have resulted in direct benefits to consumers, often with only minor monetary gains to farmers.

Other benefits to farmers have been derived from modern agriculture and the monoculture associated with it. Much farmwork is now far less tedious and laborious and opportunity for leisure is increased. In short, many

solid societal gains have resulted from changes in agricultural production systems associated with monoculture.

Nevertheless, the Task Force recognized that not all of the effects of monoculture, large-scale farming, and mechanization are desirable. Problems have arisen, or are foreseen, that cause concern. Among these are (1) increases in pests and their resistance to pesticides in some cases, (2) agricultural pollution contributions, (3) vulnerability to disaster especially when monoculture is accompanied by considerable genetic homogeneity, (4) high-energy consumption, and others.

Pest buildup.—Several generalizations can be made about the relationship between monoculture and pest incidence. Monoculture creates an environment favorable to damaging pest populations and generally inimical to the parasites and predators serving to balance these populations. In a monoculture, there is selection for those pests that can utilize the crop as a nutrient source or that are adapted to the physical environment resulting from the culture of the crop. Thus, selective pressure exists favoring a pest species. Natural forces to maintain pest populations at or below economically damaging threshold levels become less effective as monoculture increases. In such a situation, artificial methods of pest control must be used. Not to do so would defeat the purpose of agricultural production.

Agricultural pollution.—Agriculture's contribution to the pollution of the environment has received much attention during the past few years. The part of agricultural pollution that can be specifically attributed to monoculture rather than to modern agriculture generally cannot be discerned easily. Increased use of fertilizer and pesticides, a trend to large farms and to monoculture and the mechanization of agriculture all occurred at about the same time. It is logical, however, to expect that there are associations among these factors and some relationships between monoculture and environmental problems. Some of these relationships involve soil erosion, nutrient losses, and pesticide pollution.

Vulnerability to disaster.—The Task Force believed that the most important problem related to monoculture systems is their vulnerability to disaster. Monoculture practices encourage the buildup of high populations of some pest organisms, their rapid spread throughout the area and their persistence over long periods of time. Moreover, most crop species involved in monocultural systems have been the subjects of intensive plant breeding programs that resulted in varieties and hybrids with a narrow gene base. Thus, the compounding of a narrow genetic base in important crops with extensive monoculture, increases the vulnerability of the crop production system to pests, particularly diseases and insects, and to other hazards as well. Not only agricultural production is vulnerable, but also the society depending upon agriculture for food and fiber, the industries that provide production inputs and those that process and market agriculture products. History records many examples of social and economic disasters resulting from epidemic-susceptible monoculture systems.

Energy inputs.—Modern agriculture and its associated monoculture is characterized by high inputs of energy in a variety of forms. This results from the substitution of capital for labor, and machinery for horse and mule power that has occurred over the past few decades. As has been stated regarding other problems, the separate effects of mechanization or monoculture as related to high energy consumption in agriculture are difficult to identify.

Increased energy consumption is represented by the on-farm dependency on fossil fuels and electrical energy. Off-farm energy inputs required in such things as the manufacture of machinery, chemical fertilizers, and pesticides are represented also. There can be little doubt that energy expended per acre has increased markedly in the past 30 to 40 years.

The increased use of energy in the mechanization of agriculture contains some inherent dangers. In a real sense, modern monocultural agriculture is dependent upon the exhaustible resource of fossil fuel. Disruptions in foreign supplies, or a reduction in total supply of fossil fuel would materially increase energy costs and, thus, could have a serious impact on production costs of food and fiber. To this extent, agriculture is vulnerable.

Other problems.—The Task Force also identified other characteristics of agriculture that can be associated with monoculture practices. For all of these, the extent to which problems may be more important than the derived benefits is unclear. These characteristics include (1) changes in niche diversity for wildlife, (2) seasonal labor requirements, (3) economic dependency of a farm operator or an area on one or a few commodities, and (4) physical separation of production and consumption areas for agricultural products.

Considering the economic structure of this country and the life styles and food consumption habits of its people, there seems little likelihood, short of major unanticipated changes, of possible shifts from intensive to less intensive forms of agriculture. Therefore, within the constraints of adequate food, feed, and fiber production, the Task Force believed the problems associated with monocultural agriculture should be corrected rather than drastically modifying the system. Among possible approaches are (1) increased use of genetic diversity in crop production and improved pest control systems that minimize vulnerability, (2) greater crop diversity where possible, (3) strategic deployment of land to nonagricultural uses to increase spatial heterongeneity, and (4) highly managed closed or semi-closed systems in agriculture.

Whatever actions are taken to increase spatial heterogeneity or to reduce the dangers of monoculture, they will necessarily involve tradeoffs among technical feasibility, economic viability, social acceptability, and ecological stability. Changes must proceed from scientific and economic creditability; not from emotion.

Considerable new knowledge is needed to permit significant progress in alleviating the problems associated with monoculture. The Task Force made a number of recommendations for research activity based on (1) identification of research areas in which additional information is required · to correctly assess the extent of monoculture's role in environmental degredation, (2) provision of an information base for correction of problems in acknowledged problem areas, (3) definition of areas that have some potential for reversing the trend to monoculture, and (4) a few areas somewhat peripheral to the central theme.

The recommendations (without priority order) are as follows:

1. Efforts be directed toward an inventory of landscape diversity and monitoring trends in diversity.
2. A systems analysis approach to a study of spatial and temporal patterns in agricultural landscapes and enterprises be used.
3. The relationships among scale of farming, levels of technology employed, and monoculture be established by research.
4. Added research emphasis be placed on crops and on technologies that have economic potential for increasing diversity in cropping patterns and enterprises.
5. Research effort be immediately increased to halt genetic resource depletion in major crops and cropping systems.
6. Additional research effort be made in pest management.
7. Research be carried out to increase the awareness of the vulnerability of modern agriculture to energy supply.
8. The regional and national economic impact of varying degrees of failure of important crops be appraised and related to the practices of monoculture.
9. The capability to predict runoff contamination in different management systems be increased.
10. The interrelationships of land tenure and spatial heterogeneity be established.
11. The potential effect of part-time farming on spatial heterogeneity be evaluated.
12. Research be conducted on the potential of organic farming, recycling of wastes via agriculture and fuller use of agricultural residues in increasing landscape and enterprise heterogeneity.
13. Research be directed to evaluating the magnitude and seriousness of aesthetic deprivation of persons more or less constantly exposed to monocultural agricultural systems and the role of agriculture in maintaining landscapes aesthetically acceptable to urban and suburban populations.

1. INTRODUCTION

American agriculture has experienced tremendous changes during the 20th century in response to both internal and external forces. Most other segments of the economy also have experienced change, often in response to the same or similar forces.

During the early part of the century, a high proportion of the total population was rural. Agriculture was characterized by small-sized farms that could be operated by a family and the animal draft power that could be sustained on the farm. A high degree of self-sufficiency existed. The sale of agricultural products was comparatively small and purchase of agricultural inputs was limited likewise. Transportation was not well developed and comparatively costly.

Agriculture was diversified. Most farmers produced livestock and crops for on-farm human and animal consumption as well as for market. A great range of cultivated crops and seeded pastures were dispersed over the landscape in combination with forest or grassland areas. In general, fields were small with extensive interface between adjoining crops, pasture, or native vegetation.

Public research and the rate of generation of new production technology were at modest levels. Labor was a dominant production input in agriculture, while land and capital, especially capital, were relatively less important. Labor was highly physical continuing for long hours each day and 6 or 7 days per week.

Productivity per man hour, or per acre, was low in comparison with today's standards. Farm prices were established in a market place in which the farmer-producer had little, if any, bargaining power. Prices were relatively low, and consequently, the economic return to labor was low also.

Those were the "good old days." To some, who today advocate a return to a more labor intensive agriculture, they seem idyllic, but to those who grew up as a part of the labor force, they do not. But they were not to last. Strong external forces were to bring about changes that few envisioned. It seems unlikely that agriculture could return without drastic changes throughout the American economy and life style.

The industrialization of the United States, that supplied a seemingly ever-increasing volume of consumer goods, provided strong competition for low-paid agricultural labor. Wages in factories were comparatively good. Hours were much shorter than those on farms. Wars and public and private research spurred technology, resulting in new machines, new markets, and much improved transportation of goods and people. Agriculture participated in and contributed to the industrialization of America. It released labor to other industries and provided a strong market for manufactured goods. New farm machinery was developed and quickly used to replace the horse and mule as well as much manual labor. Agricultural research supplied a plethora of additional new knowledge and technology that also made significant contributions to increasing production with less labor. This technology included new crop varieties, improved fertilizers and fertilizer usage, effective pesticides, and other advances. The electrification of rural areas added a further dimension to the mechanization of agriculture.

New machines and production technology enabled farmers to cultivate more land and increase yields per acre. This required more capital, and agriculture became an industry in which capital and land were dominant inputs. Labor was released from agriculture, slowly at first, but finally in quantities larger than could be absorbed by other industries, for they also were undergoing a comparable revolution in labor-saving and technology.

Larger farms and the rapid adoption of improved production technology resulted in an oversupply of farm products. Prices fell in response to this and other forces, and profit margins per unit of production also declined. Farmers with small acreages, and consequently, a smaller volume of production were forced out of business or into off-farm employment. Neighbors acquired the land and the trend to fewer and larger farms continued and has not ceased yet. This trend encouraged disappearance of small fields and a decrease in crop diversity. To meet the demands of their highly capitalized businesses, farmers concentrated on the highest income-producing crops, often to the virtual exclusion of others.

Research produced new knowledge in many areas related to agriculture. New technologies and machinery were developed and new practices were employed often with little, if any, examination of potential environmental or social consequences. But the agricultural landscape was drastically altered and environmental and social impacts of the changes in agriculture were very real.

Modern agriculture is characterized by large scale, high inputs of energy, extensive mechanization, high usage of fertilizers and other chemicals, very high capital inputs, low labor inputs, and reduced crop diversity on many farms. Recently, agriculture has been sharply criticized as a major contributor to environmental problems resulting from soil erosion, sedimentation, loss of nutrients, accumulation of animal wastes, and excessive use of pesticides that may have deleterious effects on other than target organisms.

Concern over agriculture's role in environmental quality and its capacity to sustain itself in the future led the Institute of Ecology to recommend that "agricultural research agencies in all countries initiate experiments on the effects of increasing the spatial heterogeneity within agricultural landscapes" (Institute of Ecology, 1971). Ecologists have a working hypothesis, with considerable supporting evidence, that diversity enhances stability in natural ecosystems. This has been extended to a hypothesis, with considerably less evidence, that the homogeneity and large scale characteristic of modern agriculture results in instability from lack of predator-prey type biological control mechanisms and heavy reliance on industrial inputs such as energy, fertilizers, and pesticides.

This Task Force was to examine spatial heterogeneity in agricultural landscapes and enterprises, evaluate the costs and benefits of monocultures, consider possible alternatives, and recommend research relative to those alternatives.

A working definition of monoculture as used in this study was as follows: Monoculture exists when a single species is grown in an area in such concentration as to occupy a dominant proportion of the agricultural production of that area. The use of the word *species* is important. Planting wheat in a field is included in the definition of monoculture. The same field containing native grasses or trees would not because of the many species of plants which usually would be present. Monoculture has two dimensions—spatial and temporal. The spatial dimension is concerned with the concentration of a species or species combination within a geographic area. Temporal monoculture is the year-to-year production of the same species on the same area of land.

We have considered monoculture to be essentially the converse of spatial heterogeneity and the latter to be essentially synonymous with diversity. In general, large-scale farming and monoculture are associated, but not necessarily so. We have, with difficulty, limited our consideration to monoculture and diversity, realizing full well the existence of complex interactions between monoculture and scale.

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2. EXTENT OF MONOCULTURE IN THE UNITED STATES

Quantifying Monoculture

No ready measures of homogeneity or heterogeneity of agricultural landscapes are available. However, information theory does provide some approaches to quantifying diversity.

Diversity or heterogeneity is greatest in an agricultural landscape where all distinguishable types of land cover occur in equal areas. It is zero if the whole area is occupied by a single crop or other cover type. Any intermediate value would indicate where, on the continuous scale from homogeneity to heterogeneity, a landscape was located.

But this would be only a limited representation of the landscape pattern, whereas many variations in pattern are possible. Of two equal areas with the same proportions devoted to the same cover types, one may have each cover type segregated so that it forms a continuous block, the other may have the types distributed in a fine-grain mosaic. For example, this distinction could be represented by a series of determinations of homogeneity at different scales—and perhaps by a statistical distribution of homogeneity (or diversity) indexes for areas of different types and sizes.

Another feature of pattern that lacks a means of quantification is the neighbor and proximity relationships of different types of cover. Knowing what proportion of the periphery of areas of corn production that abuts on soybeans could be important, or, what proportion on native vegetation. Are these proportions the same for continuous corn patches of different sizes? Given a random point within a corn area, what is the average distance to: (1) The nearest point on the periphery, (2) the nearest area of soybean, and (3) the nearest area of native vegetation?

Another question concerns temporal relations of pattern. How does one quantify rotation practice in relation to the spatial pattern of a landscape? One way might be to calculate a matrix of transitional probabilities—the probability that an area occupied by crop A this year would be occupied by crop B next year.

The Task Force did not have the time or funds to develop quantifications of homogeneity and heterogeneity to any degree. They did, however, use data from the U.S. Census of Agriculture and other ready sources for information on cropping patterns.

Concentration of Crop Production

In assessing the degree and extent of monoculture in the U.S., the logical place to start is in those areas under cultivation. Uncultivated areas have considerable natural diversity of species, even though some rangeland and forests are managed so as to place limits on diversity. Furthermore, areas with a low percentage of land tilled usually have more diversity of terrain and landscape, which is associated with diversity of species.

Of 3,067 counties in the 48 contiguous States, 375 had crops harvested from over 50 percent of their land areas in 1964. Some 1,290 counties, or 41 percent, had less than 10 percent of land area in harvested crops. Figure 1 shows location of those counties having 50 percent or more land area in harvested crops.

Among the counties having high percentages of their areas in harvested crops, a few general situations or types stand out—the Corn Belt, the Upper Mississippi Delta, the Red River Valley of the North, the Texas High Plains, and the Kansas-Oklahoma Winter Wheat Belt.

Using the cropland-harvested statistic as a measure of concentration of tilled land has some limitations. First, counties vary greatly in size. Some western counties are as large as some eastern States. Although large counties may have extensive contiguous areas of irrigated land, the cropland harvested may represent a relatively low percentage of total county area. For example, Fresno County, Calif., has the highest acreage of cropland harvested of any U.S. county—almost a million acres in 1964. Yet crops were harvested from only 26 percent of its land area.

A second limitation in using the cropland-harvested statistic is that hay is counted as a crop. This includes

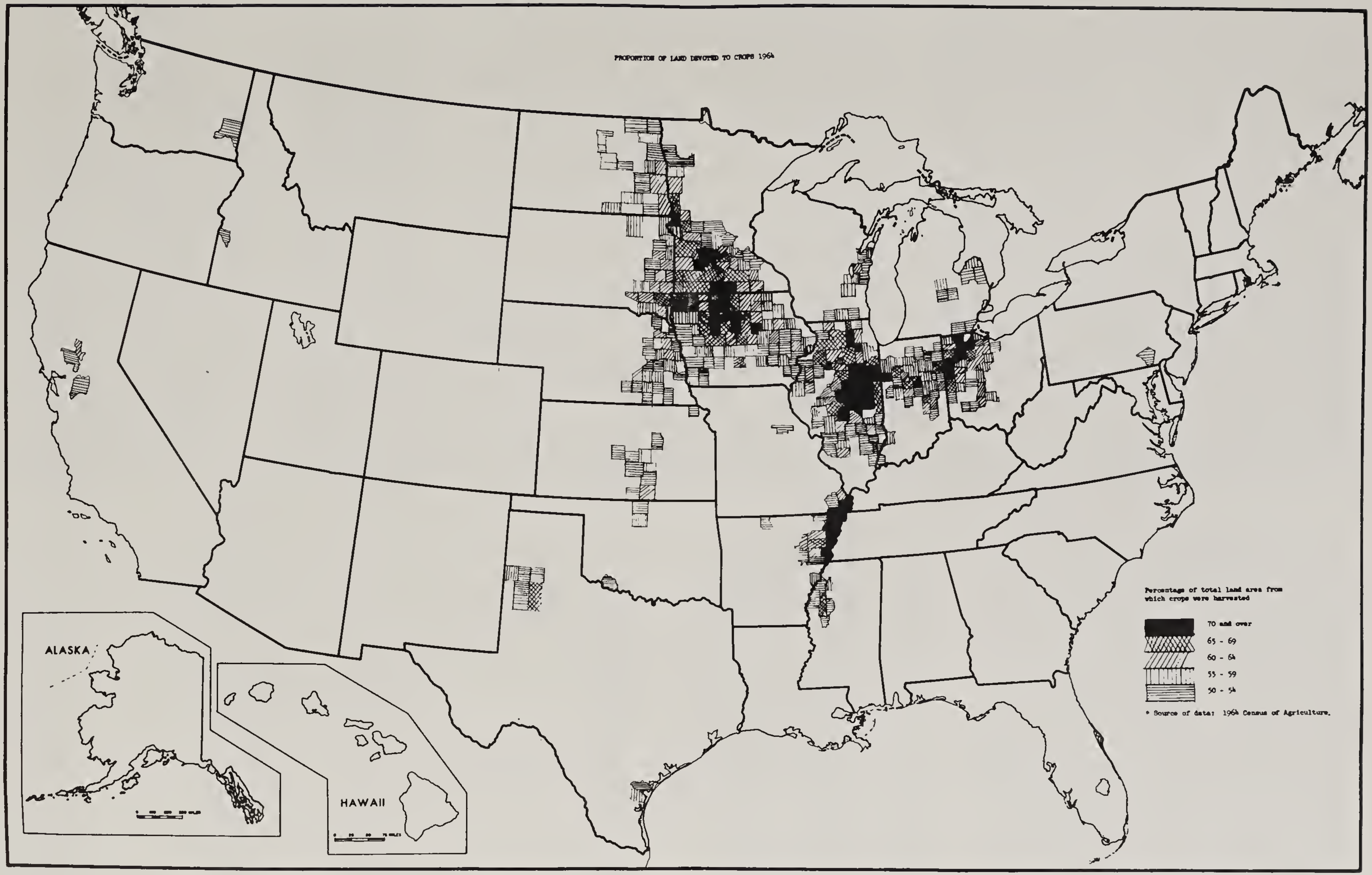

FIGURE 1.–Counties with 50 percent or more of land area in harvested crops.

some substantial acreages of wild hay that may have a species diversity approaching that of a natural state.

A third limitation is that in wheat areas a considerable acreage of land is in cultivated summer fallow. Much of it is interspersed in strips with wheat plantings. In many counties this exceeds the acreage of wheat harvested. For some purposes, the total tilled acreage, including summer fallow, is the more relevant figure to use in assessing the extent of monoculture. As an example, in 1964, Liberty County, Mont., had only 28 percent of its area in harvested crops. By including acreage of cultivated summer fallow, which exceeded the acreage of all harvested crops combined, 57 percent of the county area can be considered as intensively managed.

Trends in Concentration of Crop Production

The total acreage of land used for crops in the U.S. has remained relatively stable during this century. After increasing steadily as the West was settled, cropland peaked about 1930, decreased slightly during the droughts of the 1930's, peaked again about 1950, and since that time has been decreasing slowly (table 1 and fig. 2).

Distribution of counties by percentage of cropland harvested of total land area in 1964 follows:[1]

Percentage of cropland harvested	*Number of counties*
Over 80	1
75-79	15
70-74	29
65-69	56
60-64	79
55-59	83
50-54	112
45-49	122
40-44	105
35-39	98
30-34	128
25-29	163
20-24	164
15-19	252
10-14	373
5-9	506
0-4	781
Total	3,067

1/ 1969 Census of Agriculture data were not available on tapes readily usable for this report. However, the overall pattern most likely has not changed drastically since 1964.

However, the total national figures have tended to mask some substantial regional shifts with offsetting increases and decreases. Between 1944 and 1964, 868 counties in the United States showed increases in cropland acreage of 26.7 million acres, an average of about 1.3 million acres per year. During that same period, 2,204 counties showed a decrease of 53.5 million acres, an average of about 2.6 million acres per year (table 2 and fig. 3). Data for 1959-64 show that the trend continued through the last 5 years of the period.

New cropland appeared in many well-defined areas, associated in Florida with drainage and irrigation projects, in the Mississippi Delta with drainage and clearing, and in the Texas High Plains and Far West with irrigation development. Expansion occurred with dryland farming techniques in wheat areas of the Plains and with improved drainage and other water management techniques throughout the Corn Belt.

Abandonment occurred largely in the States to the south and east of the Corn Belt with the exceptions of the Mississippi Delta and southern Florida. Abandonment in the East resulted from low fertility and terrain features that preclude efficient use of modern machinery—many fields are small, rough, and isolated. In large areas of eastern Oklahoma and Texas, cropland reverted to grass.

Areas where production has become more concentrated are generally of more even terrain—much of it level alluvium, gently rolling loess, or glacial till. Areas going out of production have been rougher. For example, of the net of 26.8 million acres of land going out of cropland, 6.9 million were in the Northeast, 8.0 million were in the Appalachian States, and 9.5 million acres were in the Southeast—much of the latter in the Piedmont (Krause, 1970).

Cropland has shown a slight tendency toward more concentration in recent years. For example, in 1954, half the counties of the U.S. contained 86 percent of the harvested cropland while the rest had 14 percent. By 1964, this had shifted to 88 percent in half the counties and 12 percent in the remaining half (table 3, fig. 4).

Amount of Crop Diversity

To examine more closely some representative cropping patterns, eight counties were selected, one each from the five general cropping situations (Corn Belt, Mississippi Delta, Red River, Texas High Plains, and Kansas-Oklahoma Winter Wheat Belt) (fig. 1) and one each from eastern Washington wheat, California irrigation, and Montana wheat areas. From all but one of these areas, the county was selected that had the highest

TABLE 1–Cropland used for crops and crop production per acre, 48 States, selected periods and years

Period or year	Cropland used for crops				Index of crop production per acre (1957-59 = 100) 4/
	Cropland harvested 1/	Crop failure 2/	Cultivated summer fallow 3/	Total	
	Million acres				
1910-14	322	10	5	337	69
1920-24	348	13	6	367	68
1930-34	341	27	12	380	64
1940-44	341	12	19	372	80
1950	336	12	29	377	84
1951	336	17	28	381	85
1952	341	11	28	380	90
1953	341	13	26	380	89
1954	339	13	28	380	88
1955	333	16	29	378	91
1956	317	22	30	369	92
1957	316	12	30	358	93
1958	315	9	30	355	105
1959	317	10	31	358	102
1960	317	6	32	355	109
1961	296	11	33	340	113
1962	287	10	34	331	116
1963	291	10	36	337	119
1964	292	6	37	335	116
1965	291	8	37	336	122
1966	288	6	37	331	120
1967 5/	302	8	32	342	121

1/ Includes cropland from which one or more crops were harvested. Acreages are based on data from (9, 1911-67) and the annual estimates of crops harvested by SRS and predecessor agencies. Cropland used for soil-improvement crops that was not harvested or pastured and idle cropland are not included. Acreages in farm gardens, minor crops, and small farm orchards are only partially included in cropland harvested in some years.

2/ Estimates based on acreages reported by (9, 1925-45; 1964), and annual estimates of crop losses by SRS and predecessor agencies. Acreage in hay that produced nothing except pasture in some dry seasons is not included in acreage losses.

3/ Estimates were made only for land west of the Mississippi River. From 1945 to 1948, estimates were based on acreages estimated by the former Bureau of Agricultural Economics and on data issued by the Great Plains Council. For 1949 and subsequent years, estimates were based on (9, 1950, 1954, 1959, 1964); estimates of wheat seeded on summer fallow made by AMS, (now SRS) and data issued annually before 1955 by the Great Plains Council.

4/ Index numbers computed from unrounded data.

5/ Preliminary.

Source: Reproduced verbatem from Frey, H. Thomas, Krause, Orville E., and Dickason, Clifford. Major Uses of Land and Water in the United States: Summary for 1964. U.S. Dept. Agr., Econ. Res. Serv., Agr. Econ. Rpt. No. 149. November 1968.

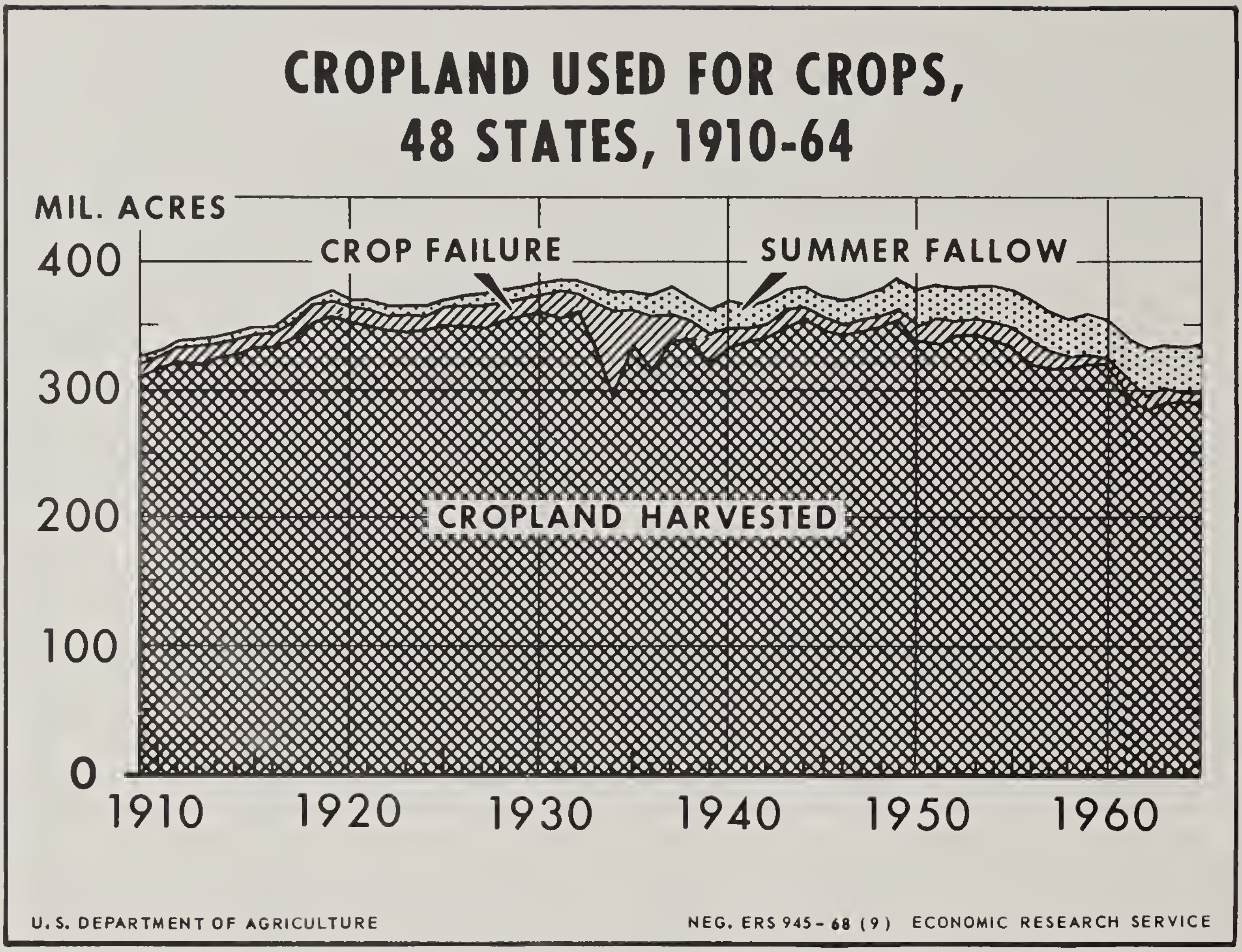

FIGURE 2.–Cropland uses for crops, 48 States, 1910–64.

percentage of area in cropland harvested. The only exception was in the Red River Valley where a county farther north was chosen to get away from the Corn Belt influence. The county in Montana had only 28 percent of its land area in harvested crops, but including summer fallow, it had 57 percent tilled or in annually harvested crops.

To get some common basis for comparing the degree or amount of diversity in different cropping patterns, a diversity index was adopted that is sensitive both to the number of different crops and to the evenness of distribution of acreage among them. The index selected is computed by summing the proportions of land in each crop times the natural log of the proportion. ($D = -\Sigma p_i \ln p_i$ where p_i is the proportion in the ith species) (Theil, 1967). With this measure, an area having its entire acreage devoted to one crop would have an index of zero. An area with 100 crops all with the same acreage would have an index of 4.60517. Ten crops evenly distributed would show an index of 2.30259.

Using this index, Liberty County, Mont., showed the least diversity. Wheat comprised 63 percent of the acreage of all crops harvested. Wheat and barley together accounted for 91 percent. Hale County, Tex., had 85 percent of crops harvested devoted to grain sorghum and cotton. With wheat, these three crops made up 98 percent. Champaign County, Ill., had corn and soybeans dominating. Pemiscot County, Mo., was weighted heavily by soybeans, cotton, and wheat (table 4).

Whitman County, Wash., had large acreages of wheat and barley plus substantial acreages of peas, lentils, and alfalfa. Sumner County, Kans., had wheat predominating, but other small grains, sorghum, alfalfa, and corn helped raise the diversity index somewhat. Walsh County, N. Dak., had wheat, barley, potatoes, oats, flax seed, alfalfa, and wild hay. Sutter County, Calif., produced a wide variety of crops, including sorghums, barley, peaches, prunes, wheat, and walnuts, with no crop really dominating. Thus, even in counties with a high proportion of land area in harvested crops, considerable ranges in diversity exist. In addition, areas of low diversity exist in some counties with relatively low acreages of harvested crops.

TABLE 2–Total cropland and counties showing changes, by regions, 1944-64

Region	Total cropland[1]		Counties showing–				Regional change (net)
	1944	1964	Increase		Decrease[2]		
			Number	Acres	Number	Acres	
	Million acres	*Million acres*		*Million acres*		*Million acres*	*Million acres*
Northeast	22.7	15.8	4	.1	240	7.0	-6.9
Lake States	41.3	39.5	72	1.2	169	2.9	-1.8
Corn Belt	80.9	82.1	288	4.6	208	3.3	+1.3
Northern Plains	92.3	93.5	132	4.7	188	3.5	+1.2
Appalachian	26.7	18.8	20	.1	450	8.1	-8.0
Southeast	24.5	15.0	35	1.0	304	10.6	-9.5
Delta	18.7	15.1	42	1.6	179	5.2	-3.6
Southern Plains	45.4	38.3	78	2.8	253	9.9	-7.1
Mountain	30.5	36.9	150	8.0	127	1.5	+6.4
Pacific	20.2	21.4	47	2.6	86	1.4	+1.2
48 States	403.2	376.5	868	26.7	2,204	53.5	-26.8

1/ Items may not add to totals because of rounding.

2/ Or no change.

Source: Reproduced verbatem from Krause, Orville. Cropland Trends Since World War II. U.S. Dept. Agr., Econ Res. Serv., Agr. Econ. Rpt. No. 177. April 1970.

Crop Diversity in Illinois: An Example of Trend Analysis

As a pilot examination of historic changes in diversity, Illinois, a Corn Belt State, was chosen and diversity indexes computed for each of nine crop reporting districts for 1938-70 (fig. 5) (Finke and Swanson, 1973). Although the same equation was used to compute the indices, it was used somewhat differently and the results are not directly comparable to those developed for the eight representative counties discussed above. The percentages of land area occupied by six major crops (corn, soybeans, oats, wheat, hay, and plowland pasture) and an "other" category were calculated for the nine crop reporting districts. This fixed the "richness" aspect of the index at seven. In this treatment, the possible range in the diversity index is from zero to 1.9459, where each category comprises one-seventh of the area.

The nine crop reporting districts in the State were grouped into four classes based on the pattern of their trends in crops diversification (fig. 6). The Northeast, Northwest, and West districts remained fairly diverse at about 1.6-1.7 until the late 1950's at which point the index began to drop sharply. The same general pattern occurred in the Central and East districts with the decrease in diversification even more pronounced. The diversification in the West Southwest and the East Southeast started at about the same level as did the Central and East districts, but the decline has been substantially less. The Southeast and Southwest districts presently have about the same level of crop diversity as at the beginning of the period, ranging from 1.287 to 1.773.

During the period of analysis, the State as a whole showed a sharp decline in oats, wheat, hay, and plowland pasture. On a relative basis, soybean acreage increased more than 400 percent and corn increased by 25 percent. Land in farms declined by over 2 million acres. The pattern of increases in acreages of corn and soybeans is reflected in the diversification indexes. This is not surprising when we view their importance. For the State as a whole, these two crops occupied 45 percent of the total land in farms in 1958, increasing to 58 percent by 1970.

Certain crop reporting districts are worthy of special note. The Central district exhibits a very steep decline in diversification. In this district, corn and soybeans occupied 53 percent of total farmland (corn was 33

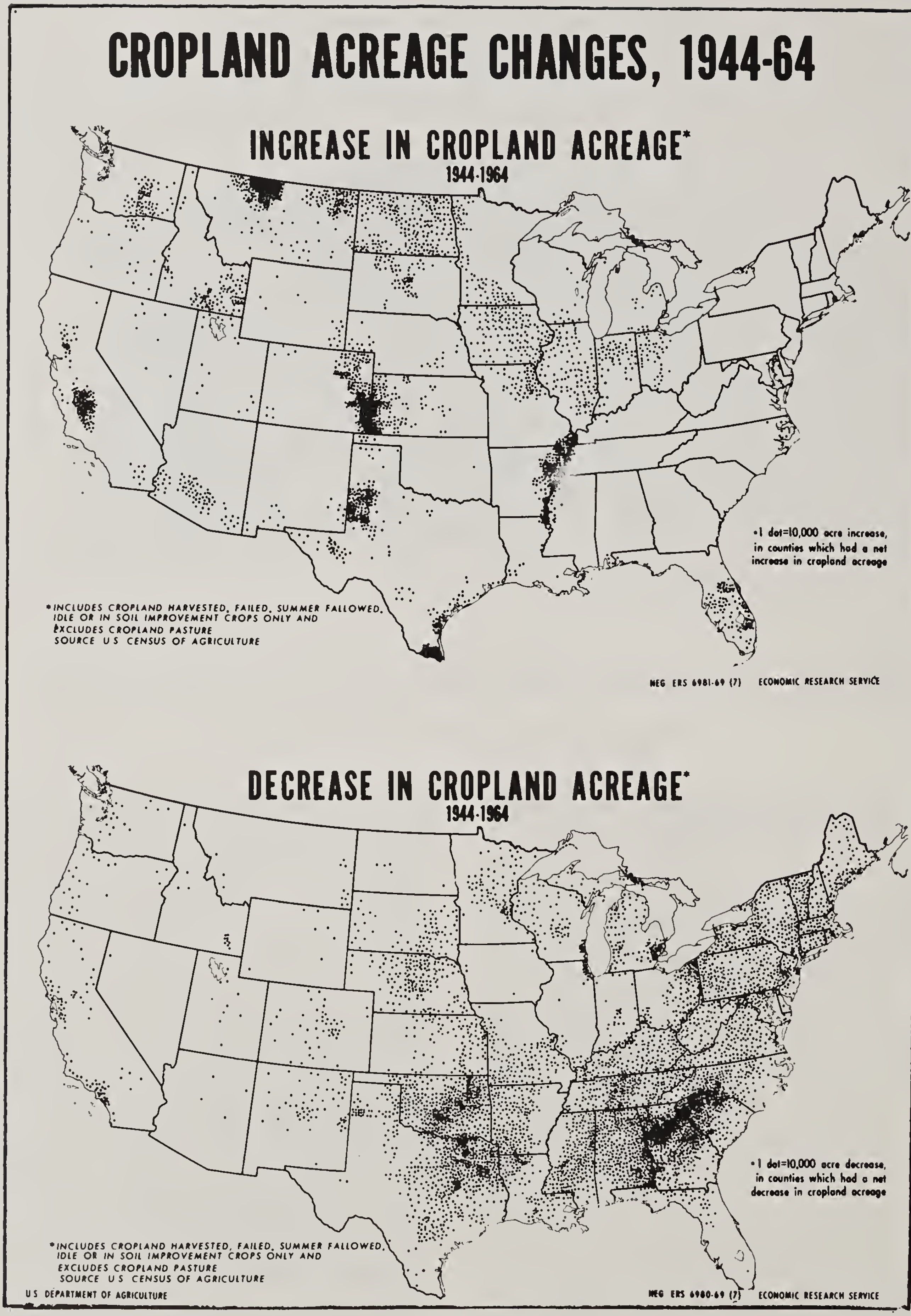

FIGURE 3.–Cropland acreage changes, 1944–64.

percent) in 1958 and 71 percent in 1970. In the East district these two crops were grown on 61 percent of the farmland area in 1958 and 76 percent in 1970.

The diversity indexes for the Southwest and Southeast districts do not exhibit any sharp downward trend. Two related reasons account for this difference. Corn and soybeans comprise only 45 percent of the total at most. Land in the "other" category ranges from 37 to 52 percent of the total farm acreage in the Southwest and from 33 to 47 percent in the Southeast.

Without question, field crop production in Illinois is becoming increasingly specialized. Farmers are primarily concentrating on two crops, soybeans and corn, which represent, at a minimum, 43 percent (in the Southwest) of all farmland to a maximum of 76 percent (in the East). Corn, alone, occupies over 40 percent of all farm acreage in the Northwest, Northeast, Central, and East. Should these trends continue without improved technology to reduce year-to-year yield variation and without greater price stability for the major crops, the risks to

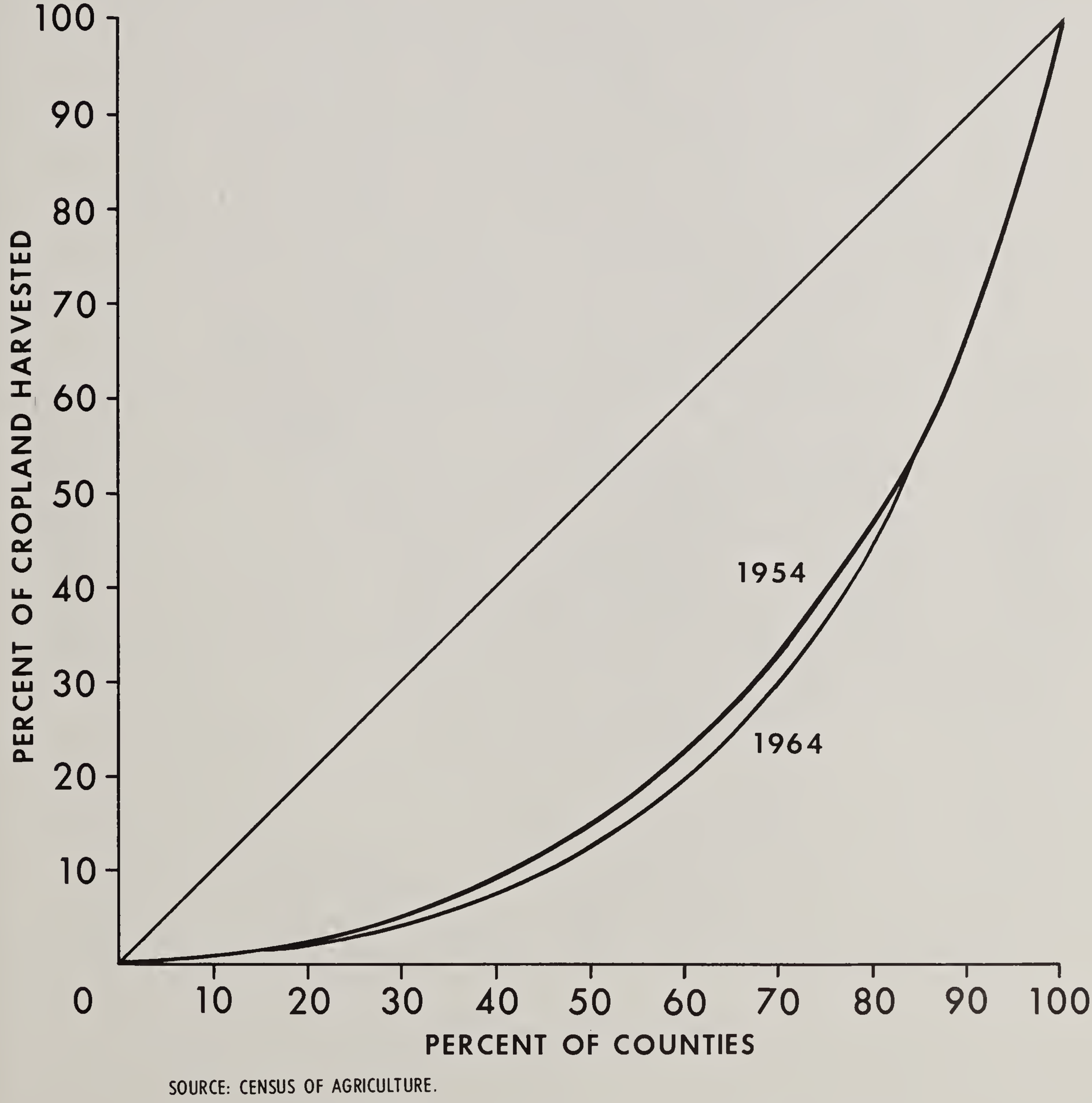

FIGURE 4.–Distribution of cropland harvested, 1954 and 1964. (Source: Census of Agriculture.)

farmers would accelerate. With no spreading of the risks through diversification, some future catastrophe could produce serious economic consequences as did southern corn leaf blight in 1970.

TABLE 3—Distribution of acreages of U.S. cropland harvested, 1954 and 1964

Percentage of counties	Cropland harvested	
	1954	1964
	Pct.	*Pct.*
10	–	–
20	2	2
30	5	4
40	9	7
50	14	12
60	22	20
70	33	30
80	47	46
90	66	66
100	100	100

Source: U.S. Census of Agriculture, 1964.

TABLE 4—Diversity indexes of representative counties, 1964

County	State	Area	Crops harvested (percent)	Diversity index[1]
Liberty	Montana	Northern Wheat	28	0.9737
Hale	Texas	High Plains	70	1.0818
Champaign	Illinois	Corn Belt	79	1.1604
Pemiscot	Missouri	Mississippi Delta	85	1.2081
Whitman	Washington	Western Wheat	50	1.2752
Sumner	Kansas	Kans. Okla. Winter Wheat	60	1.3387
Walsh	N. Dakota	Red River Valley	57	1.8161
Sutter	California	Western Irrigated	60	2.6046

1/ Applied to area of crop harvested only.

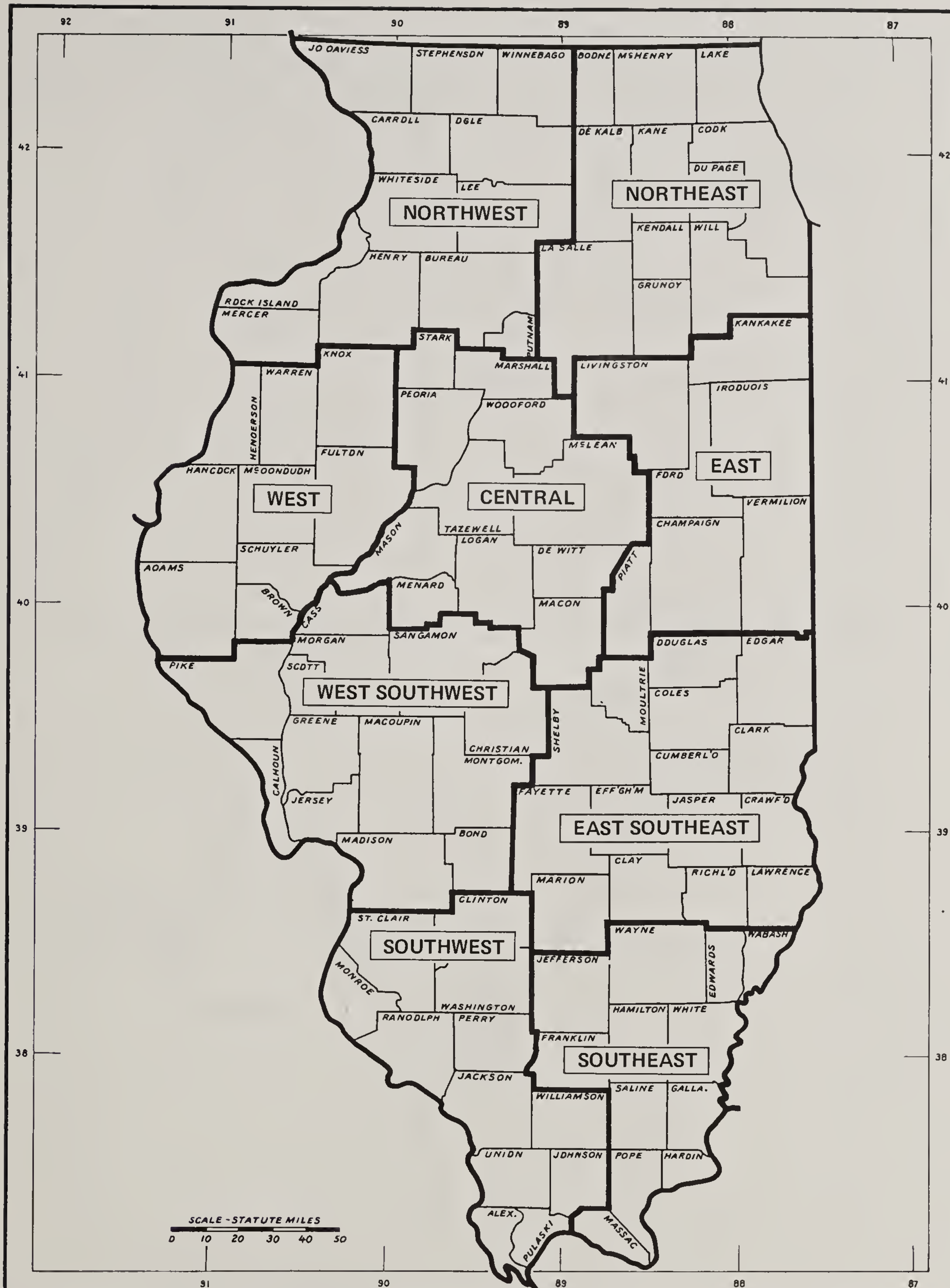

FIGURE 5.–Crop reporting districts, Illinois.

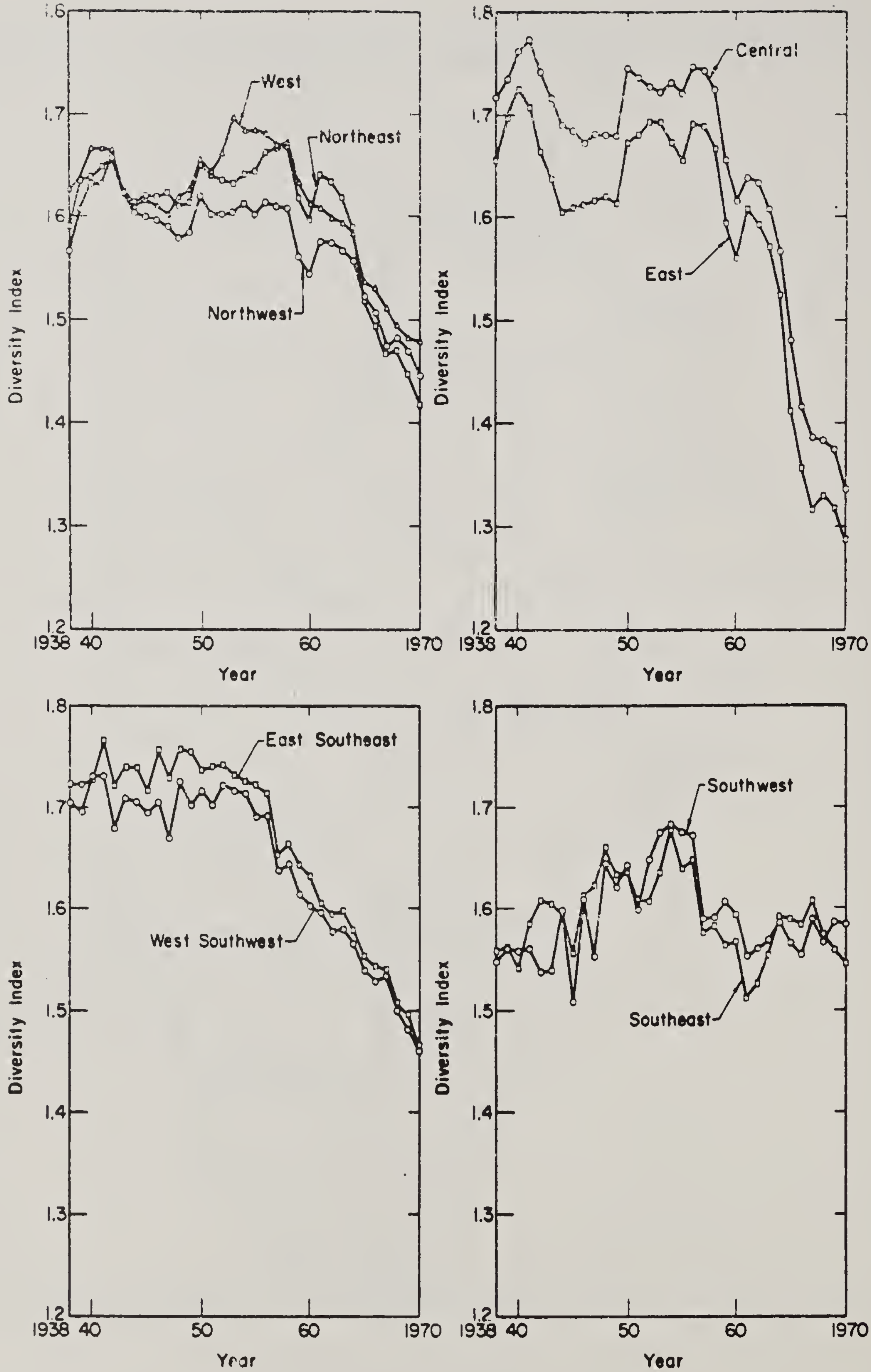

FIGURE 6.–Trends in crop diversity by crop reporting districts, Illinois, 1938–70.

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3. FACTORS INFLUENTIAL IN THE DEVELOPMENT OF MONOCULTURE

Many basic causes are responsible for development of monocultures and involve complex relationships of variables. They differ from one cropping system to another. However, some generalization regarding these causes can be made. Two specific situations are described—the evolution of agroecosystems in the San Joaquin Valley and the development of corn monoculture in the Corn Belt. Both illustrate patterns of agricultural development in response to environmental factors, new technology of many kinds, irrigation, markets, transportation, and other factors. The San Joaquin Valley has evolved through monocultures to a diversified, intensive agriculture. The Corn Belt has a marked corn monoculture.

Economic Factors

Most forces underlying the trend to monoculture have economic roots. Other motives, such as greater ease of management and more time for recreation, also influence decisions toward monoculture. But, in the main, cropping patterns trend toward greater homogeneity because, in one way or another, it pays. At the level of the individual farm, the following factors favor monoculture:

The range of crops that can be successfully grown in a particular edaphic and climatic environment is limited, and of these one or two generally yield better (in monetary terms) and more reliably than the rest.

The "success" of a crop in a particular region is dependent upon the optimization of the set of cultural practices involved in producing the crop. If this optimization has been based on large-scale operation, there are built-in pressures for the individual farmer also to grow the crop on a large scale to optimize his own results.

Managerial and labor expertise can be increased by concentrating on a single crop—particularly if this crop is widely grown in the region, and the farmer can consequently benefit from the experience of neighbors.

By devoting a large part of his property to a single crop, the farmer benefits from economies of scale. Equipment needed can be reduced in quantity; bigger discounts on supplies may be available; and arrangements for selling the crop may be more advantageous.

Difficulty in employing labor may enforce a trend to a greater reliance on mechanical aids, which are used with satisfactory economy only when the scale of operation is fairly large.

At the regional level, additional considerations apply. Again, they are broadly economic:

Increased concentration of a district on a single crop means that the agricultural organs of the district—advisers, suppliers, storage, transport, and marketing arrangements—can be more specialized, and presumably more efficient.

Some facilities will exist in the district only when the acreage devoted to a particular crop exceeds a certain threshold. This may apply to irrigation works, or to specialized storage facilities or transportation systems or processing facilities.

Concentration of research on a particular crop for a particular region has in the past depended on the presence of a substantial acreage already planted to that crop. In turn, the research results in that particular crop being still more profitable as compared with alternatives.

Increase in mean size of enterprise in the United States has gone hand-in-hand with a trend to monoculture. The causal sequences for the two trends are distinct but are mutually reinforcing. Technology favors the large-scale production of the "best" crop for the area: the farmer who grows this crop on a large scale is likely to make the greatest success of it and will be able to expand his acreage or buy adjacent properties.

Influence of Research

Research on corn culture and breeding by public agencies and private companies has contributed greatly to the establishment and success of monoculture in corn production. Corn is a crop species with high biological efficiency. Large research inputs on genetic improvement, fertilizer usage, control of pests (weeds, insects, and diseases), and mechanization of crop production, harvesting, drying, and storage resulted in technology that permitted farmers to capitalize on the biological efficiency of the species. Labor input requirements also were reduced substantially by this research. The technological developments resulting from research, coupled with guaranteed price supports, made corn the crop of highest economic return to farmers. Corn quickly became the crop investment choice of farmers, thus leading to a great reduction in diversified and especially livestock farming in much of the Corn Belt.

Recently soybeans joined corn in the Corn Belt monoculture. This crop has many husbandry practices in common with corn and much production technology could be transferred from one crop to the other with slight modification. Attractive domestic and world markets have contributed to the profitability of the soybean. Its established position coupled with an energetic commodity association have provided a base for demanding heavier research inputs. Consequently, large increases in research on soybeans have occurred in the last 5 years.

We do not intend to be critical of such research. But, obviously, technology follows research and emphasis on research on a particular crop results in increased technological development in production of that crop. It follows that allocation of research inputs among crop species has a large determining effect on the resulting cropping patterns involving those species. The development of present monocultural systems was greatly aided by the way research resources were allocated during the past decade or two. Perhaps the result could not be foreseen at the time, but the lesson is there nevertheless. Research allocation policies can have long-lasting, far-reaching effects.

Evolution of Agroecosystems in the San Joaquin Valley, Calif.

When the first Spanish explorers entered the San Joaquin Valley in 1772, they found a large population of Yokuts Indians existing on an abundance of elk, antelope, fish, tule roots, acorns, pine nuts, and other seeds. Three huge lakes formed by rivers with no access to the ocean, and their surrounding tule marshes covered most of the lowlands, at least in the spring months. Large areas of grassland and oak savannah, together with smaller amounts of saltbush desert, chapparal, and riverine communities were essentially undisturbed by man. Some insects we know today as crop pests (Western yellow-striped armyworm, alfalfa caterpillar, lygus bug, western spotted cucumber beetle, grape leafhopper, corn earworm, salt marsh caterpillar, several grasshoppers, and a number of other species) occurred there, but they could not be considered pests because no agricultural crops existed in the valley. These insects were greatly influenced by the seasonal occurrence of rain and the limited distribution of native annual vegetation. None of the Mediterranean winter annual herbs and grasses, such as bur clover, filarees, wild oat, and foxtail, were present. Crops, of course, were not cultivated.

It was not until 1836 that the first cattle ranch was established by the Spanish in the northwest fringes of the valley and these animals were produced largely for hides. During the next decade, many Spanish cattle ranches, including a few in the westside area, began a precarious existence. The discovery of gold and the rapid influx of settlers from the eastern United States created a demand for beef, and a pastoral agriculture developed. The period of 1850-70 was one of huge cattle holdings. The cattle were pastured on the lush valley grass in the winter and spring and were taken to the foothills and mountains in the summer. Overgrazing began to take its toll, especially in drought years, and the introduction of Mediterranean grasses and forbs changed the composition of the range. The white man had now developed huge pastoral agroecosystems and the indigenous Indian had virtually disappeared.

The discovery in the 1850's that the winter and spring rains were sufficient to produce tremendous crops of wheat brought on the wheat era that lasted until about 1890. The new American settlers planted huge grainfields, displacing extensive areas of the native grasslands. The crops were sent to market first by wagon to the rivers, then by barges on the rivers, and later by rail. Each increment to the railroad system increased the grain area. The full development of this wheat era was also dependent upon the invention and manufacture of gang plows, harrows, endgate seeders, and better harvesting machinery. Thus, huge grain agroecosystems were the result of an increase in the number of new settlers, a growth in market demands, more advanced transportation systems, and new technical developments as well as the natural resources of the grassland areas.

The introduction of a railroad system also permitted the development of general agriculture along the rivers where water was available. A few plantings of alfalfa were made in these "agricultural colonies" during the 1860's, but it was not until the development of irrigation systems and a dairy industry that the alfalfa acreage became extensive. The irrigation systems had small beginnings and were continually threatened by problems involving riparian rights to water, financing, land frauds, and State laws concerning water rights and irrigation districts. The dairy industry was dependent on the development of electrical power and refrigeration. Thus, the social, legal, and technical complexities in the development of agroecosystems was manifested again.

With the introduction of extensive irrigation systems, the grasslands and alkali deserts of the San Joaquin Valley were transformed into an intensive irrigated agriculture. Along with the grains and alfalfa came tree fruits (deciduous and citrus), grapes, cotton, melons, sugar beets, rice, and vegetables. A variety of native insects found the lush irrigated fields or orchards an ideal haven. An abundant food supply was available the year round and their period of increase was no longer confined to the spring. To the native pest fauna has been added an array of immigrant species such as the alfalfa weevil, spotted alfalfa aphid, pea aphid, green peach aphid, cotton aphid, codling moth, peach twig borer, Oriental fruit moth, citrus red scale, and olive scale.

Each addition brought about significant changes in the agroecosystems. At the same time agricultural technology and agronomic practices were improving. Better land-leveling equipment produced better seedbeds and improved water flow and distribution. This resulted in better crop stands and fewer weeds. The use of fertilizers and new plant varieties increased yields and reduced diseases. Mechanization sped up harvesting.

Each of these changes had its impact on the insect populations in the agroecosystems and often changed the pest problems. For example, with alfalfa, the newer mowing machines leave a higher stubble, the new varieties have more leaves low on the stems, and better irrigation techniques bring water into the field soon after harvest. As a result, the alfalfa field is not a barren desert following each summer harvest and more insects—both beneficial and harmful—are able to survive from one cutting period to the next. This continuity of the insect populations favors stability and decreases the chance of pest outbreak.

With all the change that has occurred in the San Joaquin Valley, one would think that a stable state finally has been reached. Today, the Indians, the lakes, the tules, the elk and antelope, the oaks and salt bushes, and the native grasses and herbs are gone. In their places are hundreds of thousands of human beings, crops and exotic weeds, domesticated livestock, wells and dams, irrigation and drainage systems, cities, industries, railroads, airports, and highways. But the system continues to change. More people arrive, cities expand, freeways emerge, industries proliferate, wastes accumulate, wells deepen, new crops are planted, agrochemicals evolve and diversify, new pests appear, water tables drop, agronomic and horticultural techniques change, and agromechanization becomes more sophisticated. Characteristically, each change has impact that ramifies broadly in the whole system and this has a profound influence on man.

For example, production of cotton, alfalfa hay and seed, small grains, safflower, tomatoes, potatoes, and other crops is almost totally mechanized. One unusual feature is that, with the exception of those engaged in service employment, people have almost disappeared from the west side of the San Joaquin Valley.

Unquestionably, during the next decade many more changes will occur that affect land use and cropping practices. Already, thousands of acres of various vegetables are being planted to replace small grains and the dairy industry is slowly moving out of the Los Angeles basin into the valley. Such changes may, in part, reverse the trend of the unpopulated monocultural system.

Growth of Monoculture in the Corn Belt

The Corn Belt was settled largely after the completion of the rectangular land survey and after the Homestead Acts. The 160-acre unit consequently became the model for operational units. The earliest economy was based largely on cattle grazing, with the grazing industry moving westward from Pennsylvania to the western Dakotas and Nebraska at a rate of about 20 miles per year. Following the cattle era, wheat was predominant, giving way in turn to a more diversified system utilizing corn, small grains of several types, and forages. Not only were crops diversified but animal production included sheep, hogs, poultry, beef cattle, and some dairy cattle, at least enough for milk for home consumption.

A family, in the years before World War II, could do reasonably well on 160 to 320 acres of fertile land in the Corn Belt. Self-sufficiency through producing the family food supply on the farm, raising one's own horse or mule power, and feeding the draft animals from the land was the vogue. Diversifying crops and livestock enterprises was recommended to provide for crop rotation as a soil conserving measure, to build organic matter and nitrogen, restrict and discourage disease and insects, and to provide for an efficient distribution of labor. A typically sought-for rotation was the corn, corn, oats, and clover—a 4-year system popular in the level lands of northern Illinois and Iowa. Although few attained and maintained a systematic year in and year out cropping pattern, such rotations were the ideal and an earnest attempt was made to avoid more than 2 or 3 years of corn. Corn was followed by a legume seeded in oats as a nurse crop. Clover was left down a second year to be plowed under for a green manure before again planting corn.

Corn was picked by hand. One man working alone and throwing the picked, shucked, clean ears of corn against a "bang board" in a wagon pulled by a team of horses trained to keep pace with the picker could harvest about 100 bushels a day. Thus, on a 160-acre farm in a 4-year rotation, a farmer and his son or his hired man could be expected to harvest two 40-acre fields in a 4-year rotation by Thanksgiving–that is, before snow time.

As recently as 40 years ago, horses and mules were still abundant. There was a large need for forages and the diversified farm, rather than the specialized farm, was generally advocated. A man needed to spread his labor because he did not have fast moving power machinery to handle a large acreage of a single crop within the narrow seasonal limits of its planting and harvesting times. Units of machinery were relatively inexpensive, so that being prepared to handle several crops, even on a small farm, did not call for excessive capitalization. Nitrogen and other nutrients were expensive, farm prices were low, farm products and labor were cheap, and money was dear. The idea of building the land with manures, nitrogen from legumes, lime, and "other nutrients as needed" fitted well into a land-use pattern that in turn permitted high efficiency of the human, animal, and machine power available.

About 1930, the country was in a deep recession from which would emerge a revolutionary political philosophy to have profound influence on the attitudes and activities of farmers. Land use and conservation were suddenly to become items of public policy. Agriculturists were soon asked to provide the principles to guide a national land policy that would have tremendous educational implementation.

Following the Mississippi flood of 1927, Congress appropriated funds for several cooperative State-Federal soil conservation experiment stations. A few stations were soon established under the Division of Agricultural Engineering in the Bureau of Public Roads and the Bureau of Chemistry and Soils.

In 1935 the Federal share of this program was transferred to the Soil Conservation Service. Data were soon forthcoming that showed outstanding reductions in soil and water loss when terracing, contouring, and strip cropping techniques were used (Musgrave and Norton, 1937). Grass was found to protect soil more than legumes, and legumes more than row crops. The relative efficiency of different cropping patterns for soil protection was worked out (Bennett, 1939). Typical of the data are the results from Clarinda, Iowa, showing an annual loss of 0.06 ton of soil and 0.97 percent of the rainfall from grass, 5.4 tons and 4.95 percent from rotation, and 18.8 tons and 8.6 percent from corn.

Studies at these Soil Conservation research stations on the influence of cropping systems and soil management practices on soil organic matter content and soil structure showed the deterioration of both to be high under continuous row cropping, less under a rotation, and almost negligible under continuous sod (Johnston and others, 1943; Wilson and Browning, 1946). Although the techniques of contouring, strip cropping, and terracing were known in the 19th century, research at the Soil Conservation research stations refined this knowledge and provided specific data for individual regions.

In the rapidly developing national programs for land use and conservation under the New Deal, national organizations were established with the capacity to influence the individual land management on every farm. Among the organizations concerned with land use policies, which were initiated more or less concurrently with the Agricultural Adjustment Administration of 1933, were the Soil Erosion Service, soon to become the Soil Conservation Service, the Civilian Conservation Corps, the Works Progress Administration, and the Tennessee Valley Authority (Harper, 1951). Those expediting and executing these programs had to make immediate judgments as to proper land management. This gave tremendous significance to the ideas and judgments of agronomists based for the most part on the fertility experiments of the preceding 25 years and the soil conservation studies of the preceding 5 years. The agronomists of those times naturally developed land use programs favoring rotations containing legumes and high in the proportion of meadow crops compared with row crops.

World War II brought a shift of emphasis to top production of many so-called "soil depleting crops." With the cost of labor suddenly very high and the supply minimal, there was real incentive to maximize the mechanical possibilities that the automotive age had developed for farmers forced to handle large tracts. With the boys gone to war, dad found he could increase his operating unit tremendously if he had good equipment and stayed on the tractor seat. High prices for such crops as corn, small grains, hemp, and cotton made him impatient with rotations. He experimented with higher rates of fertilizer and became more and more interested in the slowly accumulating results of research with the higher rates and the easy, rapid ways of applying fertilizer.

During this period, the use of commercial fertilizer for general agronomic crops increased rapidly. The way had been paved by agronomic research on high rates of fertilizer for corn. The gradual development of the philosophy behind the current recommendations for high rates of fertilizers merits attention. The use of high rates of fertilizer on truck crops, tobacco, citrus, and other special crops had been common for some time. Even though using inadequate amounts, cotton farmers (Westbrook, 1926) used fertilizers at higher rates before the war than did corn farmers.

The innovations by farmers and researchers in the Corn Belt during and immediately after the war led to important changes in corn culture. Research demonstrated conclusively that increases in yield were possible from higher rates of fertilizer, particularly nitrogen, and from deep placement of starter fertilizers (Cook and others, 1940; Scarseth, 1943; Yoder, 1943; Yoder and others, 1943; Drake, 1944; Scarseth and others, 1944; and others). Other research showed that higher plant populations were necessary for maximum yield response to fertilizer (Lang and others, 1956).

Changes in fertilizer practices encouraged a review of rotations and modifications of old-line fertility experiments (Purdue University, 1952; University of Illinois, 1957). This new evidence substantiated the opinion of many farmers that, on relatively nonerodible land, they could grow corn more years in succession without soil deterioration than was recommended in the commonly used soil conservation handbooks (Melsted, 1954; Peterson, 1955; Smith, 1952). Other results presented questioned the economics and actual benefits to the soil of growing legumes in a corn cropping system compared with adequate fertilizers and continuous corn. Other research (Melsted, 1953) emphasized the need for fertilizer to produce high yields, and that if the large quantities of organic matter produced were incorporated into the soil, commercial nitrogen could substitute for legumes in maintaining soil structure and organic matter levels. Thus, on suitable land, continuous corn production became economically much more profitable than previously believed.

Research on corn culture in the 1940's and 1950's—of which the foregoing examples are typical—accompanied by new high-yielding hybrids and the development of efficient farm machinery contributed greatly to the growth of monoculture in corn production. Improvements in the mechanics of planting, controlling weeds and diseases, harvesting, drying, storing, and transporting corn led to ever increasing size of operation as the improvements in yield per acre were rapidly capitalized back in land values.

The growth in farm size and changes in farm operations resulting in part from changes in corn culture, are well documented in recent publications based on data from the U.S. Census of Agriculture, the USDA's Statistical Reporting Service, and other sources and will not be elaborated on here. Many knowledgeable individuals are aware of the continuing decline in farm numbers and the increasing concentration of production on larger farms. They are also concerned that these large-scale production units are becoming more involved with integrated or contractual arrangements to market their products through industrialized "food systems," such as conglomerates, which may some day rival the concentration of economic power now present in much of our industrial economy. These developments could point to a future time, perhaps only two or three decades away, when the sole proprietorship and the typical family-scale farm unit of the past will have essentially vanished from the U.S. commercial farm scene.

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4. PROBLEMS OF MONOCULTURES

Monoculture is characteristic of much of the intensified production of food, feed, and fiber in the United States. Development of monoculture was accompanied by a reduction in the number of farms and an increase in their average size. The trend to larger farms has facilitated and, in part, been caused by a rapid trend to mechanization. These events have been accompanied by a large increase in purchased energy in the form of fossil fuels and in other production inputs such as fertilizer, pesticides, and electricity.

There are many causes of these changes. One important cause was the necessity to expand production volume when margin per unit of production decreased. Some farmers could not, or chose not to, expand; others did so by greatly increasing their investments in such things as land and equipment, with parts of the added investment capitalized in increased land values.

Basically, the changes that occurred enabled farmers, by employing high levels of technology and managerial ability, to achieve the highest return on investment capital. In so doing, they have provided a continually increasing volume of high-quality food, feed, and fiber to the American public at relatively low costs—something like 16 percent of consumer income is spent for food. The continued low overall cost of food and fiber, despite increasing product demand, is a direct benefit to society from large, mechanized farm units and the associated monoculture. For the most part net income has risen more slowly in the farm sector than in the nonfarm sector of our economy. Actually, decreased production costs have resulted in direct benefits to consumers often with only minor monetary gains to farmers.

Other benefits to farmers have been derived from modern agriculture. Much farmwork is now far less tedious and laborious, and opportunity for leisure is increased. Farmers now enjoy many cultural amenities enjoyed by urbanites. In short, many solid societal gains have resulted from recent changes in agricultural production systems. But not all the effects of monoculture, large-scale farming, and mechanization are desirable. Problems have arisen, or are foreseen, that are more or less directly related to monocultures and many are inextricably interwoven with scale of farming and mechanization. The following discussion documents some of these problems.

Pest Buildup and Resistance to Pesticides

Any natural ecosystem arrives at a state of relative stability through an evolutionary process. Early in its development, the ecosystem is characterized by wide amplitude of population fluctuations of its component species. As the evolutionary development continues, this amplitude decreases because the component species, which are not the same as those in a lower seral stage, are better adapted to the physical environment and to the interactions of the biological community. Thus, the mature ecosystem represents a harmonized amalgam of interdependent species attuned to a specific set of interactions. This assures the presence of a single species within a narrow population amplitude.

Cultivated agriculture mimics a natural ecosystem at a subclimax stage, thereby increasing the amplitude of its component species. The extreme situation, a monoculture, is the least stable because those species adapted to the crop or to the cultural requirements of the crop are favored. Others that contribute to a balancing of populations do not survive. In a monoculture, there is selection for those pests that can utilize the crop as a nutrient source or that are adapted to the physical environment resulting from culture of the crop. Thus, selective pressure exists favoring a pest species. In such a situation, artificial methods of pest control must be used. Not to do so would defeat the purpose of the agricultural system.

Monoculture, in a spatial sense, is a situation in which one crop occupies most of the cultivated acreage, being interspersed with other crops, vegetation along fence rows, or with natural communities such as woodlands, native grass, or the like.

In a temporal sense, a crop is often rotated with another having a different set of associated pest species. Indeed, crop rotation is sometimes a requirement of successful crop culture because of the continued pest buildups resulting from monocropping. For example, continuous cropping of corn or other host grasses, contributes to the buildup of a complex of soil insects adapted to the host crops, the corn rootworm being of critical importance. Certain species of host-specific nematodes can be kept at economically acceptable population levels by crop rotation. Without resistant crop varieties, the semicontinuous culture of soybeans and potatoes would be prevented by the soybean cyst nematode and the golden nematode, respectively. Southern corn leaf blight became epidemic because most of the hybrid corn had a common cytoplasm, and the fungus pest broke resistance to that cytoplasm.

Especially since the introduction of synthetic, organic pesticides, farmers have developed a dominant reliance on pesticidal control of pests with a concomitant reduction or exclusion of other methods. Because of their effectiveness, pesticides may be responsible for contributing to an increase in monoculture. Agricultural scientists have long recognized, however, that repeated applications of pesticides often result in resistant populations. The pesticide acts as a selective force. Susceptible individuals are killed, while those that are resistant survive and pass on their resistance to their offspring. Certain populations of about 230 insect species are known to be resistant to one or more pesticides (Conway, 1971). Two important examples are resistant cotton pest populations in Mexico (Adkisson, 1969) and in the Canete Valley of Peru (Conway, 1971). Other examples can be cited that are less dramatic, but which, nevertheless, collectively demonstrate that sole reliance on chemical pesticides for the control of pests is inimical to the needs of agriculture. Indeed, reliance on any single method of pest control is doomed to failure. A characteristic of biological organisms is their adaptability. Any single pressure directed against an organism will be circumvented by one mechanism or another.

Although clearcut examples of resistant weed populations cannot yet be substantiated, there is no reason to expect that resistant populations will not develop. That they have not probably is simply a function of the longer life cycle of plants. Although resistant populations of weeds have not developed, several examples of shifts in weed populations resulting from repeated treatments with specific herbicides exist. For example, nutsedge was a principal weed in peanut production. The use of nitralin controlled the nutsedge, but now prickly sida is a greater problem than before. Similarly, grasses became a greater problem in corn production because phenoxy herbicides controlled the broadleafed weeds.

Several generalizations can be made about the relationship between monoculture and pest incidence as follows:

- Monoculture creates an environment favorable to damaging pest populations and generally inimical to the parasites and predators serving to balance these populations.
- Interplanting with a second crop is a useful technique often because parasites and predators of the pest in the prime crop may have a favorable habitat in the second crop (Stern, 1969).
- The likelihood of naturally maintaining pest populations at or below economically damaging threshhold levels increases as crop diversity increases. However, natural forces will not usually satisfy agriculture's need for crop protection.
- Because pests will adapt to a given control practice, methods of integrating the available control technology into a system of crop protection—protection against all classes of pests—is the desirable course for research in the future.

Agricultural Pollution

Agriculture's contributions to pollution of the environment have received much attention during the past few years. This focus came first from outside agriculture and principally from ecologists and associated groups. Seriously challenged were the environmental insults from agriculture relating to (1) sedimentation, (2) loss of nutrients and their movement into watercourses and lakes, (3) movement of pesticides from fields by various means and their incorporation through various food chains into nontarget organisms, including humans, (4) improper disposal of animal and other agriculturally related wastes, and (5) a myriad of other challenges mostly of lesser significance.

The part of agricultural pollution that is specifically attributable to monoculture rather than to modern agriculture generally cannot be discerned easily. For example, we don't know that excessive use of fertilizers and pesticides is necessarily associated with monoculture. Certainly, there are instances in this country where these two production inputs are very large in highly diverse agriculture, and there are also countries, such as Japan, where in a highly diverse landscape, fertilizer and pesticide usage far exceed that in the United States.

Increased use of fertilizer and pesticides, the trend to large farms and to monoculture, and the mechanization of agriculture all occurred at about the same time. It is logical to expect that there are associations among these factors and that there are some relationships between monoculture and environmental problems. Some of these relationships are discussed as follows:

• *Sedimentation.*—Sedimentation is the greatest pollutant of water in terms of volume. Mass loading of sediments in streams has been estimated at 500 to 700 times that of sewage (Robinson, 1970). Agriculture accounts for about half the erosional sediment (Wadleigh, 1969). Crops that provide a tight vegetative cover for the soil surface minimize erosion. Conversely, clean tillage of crops, like corn, cotton, and soybeans, leaves the soil surface exposed for considerable periods of time and facilitates erosion. Some crops, notably soybeans, are noted for rendering surface soils especially susceptible to erosion. These are the most profitable crops in many areas and are, consequently, often grown in monocultures.

The longer a slope is without interruption the greater the volume of runoff following rain and also the greater the volume of soil loss. This is especially true on steeper slopes but also true on long slopes as gradual as 2 or 3 percent.

Monocultural production of clean-tilled crops could be expected to have an accelerated effect on erosion losses unless adequate countermeasures were employed. Large fields of a single, clean-tilled crop mean long slopes exposed to rain and action of moving water and, consequently, immense soil losses in periods of heavy rainfall. The loss would be particularly severe on slopes of highly erosive soils and on steeper slopes of almost any soil type. There can be little doubt that increased tendencies to monoculture of clean-tilled crops has a positive relation to soil loss. This is particularly true with certain crops grown in monoculture on highly erosive soils under high rainfall conditions.

Certain countermeasures are useful in reducing erosion losses. Contour planting, strip-cropping, terraces, minimum tillage, and similar practices are effective. Sod-seeding of corn also reduces exposure of the surface to erosion. High plant populations of corn quickly form a protective canopy and reduce impact and erosive force of raindrops. The large crop residue in modern corn production protects the soil surface and, when plowed down, increases organic matter content and absorptive capacity of the soil. Despite the use of such protective measures, albeit not universally, the loss of soil is accelerated by monocultures. For example, sediment yields in the Mississippi basin that average approximately 400 tons per square mile annually (Robinson, 1970) attest to that.

• *Nutrient losses.*—Nutrient losses from agricultural activity have been charged with responsibility for the decreasing quality of water in lakes, streams, and wells. The nutrients involved are primarily phosphorus and nitrogen, although potassium, calcium, and magnesium may also be lost in substantial amounts. Significant amounts of these nutrients are applied in commercial fertilizers and the amounts applied have increased markedly in recent years. Furthermore, heaviest applications have been on clean-tilled crops of highest value; relatively small amounts are applied to forages.

Nutrient losses occur largely through water runoff or through leaching. Water runoff may contain nutrients—nitrogen and potassium mostly dissolved in the water, and phosphorus and others adsorbed on suspended soil particles. These nutrients can come from the soil itself (for example, derived from applications of commercial fertilizers), from animal wastes spread on land or from feedlots, or from other organic matter suspended in the runoff.

Leaching involves principally nitrogen because phosphorus is quickly fixed to soil particles and does not move with percolating water. Sources of nitrogen are those mentioned above and bacterial decomposition of organic matter in the soil.

The extent to which monoculture, as contrasted to a diverse cropping pattern, affects loss of nutrients, is related to the degree to which this practice results in greater runoff, or to greater applications of chemical fertilizers subject to loss by erosion and by leaching. In addition, feed grain monocultures often mean separation of grain production and consumption. Grain may be produced by some farmers and sold to others or to feedlot operators. This results in a concentration of animal wastes, as contrasted to diversified agriculture, and consequential disposal problems that are susceptible to rather large nutrient losses.

The role of monocultures in increasing runoff was described above. The relation of monoculture and rate of fertilizer application is not clear or well documented. It seems logical that the highest rates of fertilizer application are on crops that are important in monocultural systems. However, this could prevail even in a system of considerable spatial heterogeneity. Thus, monoculture's contribution to increased nutrient pollution apparently would come largely through increased runoff and the associated loss of nutrients and to a relatively small extent via leaching and contamination of wells and groundwater. However, we must repeat that there is little documentation of monoculture's role in nutrient losses from agricultural activity.

• *Pesticides.*—Few issues related to agriculture today elicit the same degree of emotion and concern as the issue of pesticides. For much of the public, pesticides are equated with DDT and other persistent chemicals that are widely distributed, remain in the environment for long periods of time, and result in residues in food and feed. Yet, most pesticides degrade rapidly.

We are concerned here with the part of pesticide pollution that is a consequence of monoculture. Two crops, corn and cotton, offer interesting cases in point.

Corn production is affected adversely by a complex of insects (corn borer, corn rootworm, cutworms, wireworm, and others), diseases and nematodes, and various weeds. Pesticides are used to control these pests.

The soil insect complex is particularly troublesome because the insecticides used to control these pests must be applied on a preventive basis. Methods have not yet been developed that permit an assessment of soil insect populations followed by a rational decision to use, or not use, an insecticide. Thus, the producer is faced with the dilemma of making a subjective decision to (1) apply an insecticide on a preventive basis, or (2) take the chance that damage from the soil insect complex will not occur.

Aldrin is the insecticide most commonly used to control the soil insect complex that adversely affects corn production. Even though the corn rootworm has developed resistance to aldrin in the western half of the Corn Belt, aldrin is still the insecticide of choice for controlling other species of the soil insect complex. Consequently, an estimated 80 percent of the aldrin used in agriculture is used in corn production.

If agriculture in the Corn Belt were shifted to a more diversified cropping pattern, the amount of aldrin used for crop protection probably would be reduced, but would not be eliminated. Some insects, particularly the corn rootworm, are quite specific in their food habits. Others, such as cutworms and wireworms, attack a wider variety of crops. The degree of insect control that could be obtained by crop rotation and other cultural practices in a diversified system is unknown.

Atrazine is the principal herbicide used in corn production. It controls a wide variety of weed species without affecting the growth and development of corn. Although much less persistent than aldrin, atrazine has occasionally remained in the soil at residue levels sufficient to affect soybeans and certain other crops the following year. In addition, the composition of weed species in corn is shifting in favor of those species more resistant to atrazine. Thus, we can probably look forward to the use of a wider variety of herbicides and herbicide combinations for weed control in corn production. A more diversified agriculture in the Corn Belt would probably result in the use of a broader array of herbicides.

Cotton approaches a monocultural system most nearly in the South, particularly in the Mississippi Delta region. In that area, various insects attack the crop, but the key pest species are the boll weevil, cotton bollworm, and budworm.

Despite the development of resistance to certain pesticides in some cotton growing areas, pesticides are still needed in cotton production. Shifting to a more diversified agriculture may reduce the total volume of pesticide usage while at the same time requiring a wider variety of pesticides. The kinds of insecticides needed in replacement crops would depend on the nature of those crops.

Two basic considerations in discussing the use of pesticides in monoculture as opposed to their use in a diversified agriculture are as follows: (1) Are more or fewer pesticides used in monoculture than in a diverse cropping system; and (2) what is the relative volume of use?

In the first, a diverse crop system provides a wide variety of hosts for pest species. Thus, one would expect a relatively greater pest diversity as well. If only chemical control is considered, then surely a broader array of pesticides would be necessary to control the pests. But crop diversity also provides for a wider variety of beneficial insects that serve as control mechanisms for destructive insects. Experience tells us that natural control processes are not adequate to maintain pest damage below economic levels, and that some method of control must be used. If reduction of pesticide use is an objective, then systems of crop protection must be developed that will utilize all pest management technology. Because that technology will vary for each crop, the solution to pest problems may be more difficult with a diversified system than with a monoculture. However, there is also the probability that crop diversity will reduce the population amplitude of pest species. That situation would require less sophisticated systems of crop protection.

Several examples are available of greatly increased natural control resulting from diversified cropping systems. Research in this area needs to be expanded.

Essentially, the same logic applies to the second consideration. If crop diversity does, indeed, lead to stability (lesser amplitude) of pest populations, then the volume of pesticide use will be reduced. There are, however, a host of variables that influence crop-pest relationships. Modeling studies on systems of crop protection are critically needed.

Vulnerability to Disaster

Monocultural agriculture implies the production of a crop species over large contiguous areas, or on the same area for several years. Frequently, a single crop is grown over the same large contiguous area for several years. Such practices encourage the buildup of high populations of some pest organisms, their rapid spread throughout the area, and their persistence over long periods of time.

Moreover, most crop species involved in monocultural systems have been the subjects of intensive plant breeding programs that have narrowed the gene base of the species. As a result, most major food crops of the world now have a relatively narrow genetic base (Harlan, 1972; National Academy of Sciences, 1972). This base has resulted partly from the plant breeder's success in developing varieties of superior yielding ability when grown with a specific set of cultural and mechanized systems. Superior varieties of self-pollinated species are widely grown and a single genotype may be grown over thousands of acres, often contiguous. In maize, a cross-pollinated species, a relatively few inbred lines are common to many hybrids and the genetic diversity in the crop is much less than generally realized. The use of a common cytoplasmic sterility in maize resulted in almost our entire acreage of the crop having a single cytoplasm. The technique now is being extended to other crop species.

The compounding of a narrow genetic base in important crops with extensive monoculture, as in corn, soybean, and wheat production, for example, exposes the system to extreme vulnerability to pests, particularly diseases and insects (Apple, 1972). A National Academy of Sciences Committee has stated that "Crop monoculture and genetic uniformity invite epidemics. All that is needed is the arrival on the scene of a parasite that can take advantage of the vulnerability (National Academy of Sciences, 1972). Not only agriculture is vulnerable, but also the society dependent upon agriculture for food and fiber; the industries that provide production inputs, and those that process and market agricultural products.

Another aspect of vulnerability not often considered is the extreme vulnerability to biological warfare inherent in an agricultural production system in which monoculture and genetic uniformity are prevalent. The release of virulent races of disease organisms in such a system could have catastrophic consequences, particularly if weather conditions were favorable. Although this is unlikely to occur, such a possibility cannot be ruled out. Man has used all available technologies in warfare—many of them more hideous than this. We should be cognizant of this risk and take steps to alleviate it.

History records many examples of social and economic disasters resulting from epidemic-susceptible monoculture systems (van der Plank, 1960). Possibly the most famous is the Irish potato famine of 1845-49, resulting from the almost complete loss of the potato crop to the fungus disease, late blight. Here, a destructive, endemic disease organism attacked a newly introduced plant that had no resistance—a not uncommon situation in modern agriculture. Other examples of disease epidemics in such monocultures as wheat, coffee, natural rubber, and bananas that have caused disastrous losses are discussed by (Carefoot and Sprott, 1967).

Where resistance to insect pests is lacking, monoculture of field and horticultural crops has sometimes led to calamitous crop destruction. The cotton boll weevil caused losses estimated as high as a billion dollars in a single year in the United States as the insect swept into Texas from Mexico around 1900 (Metcalf and Flint, 1962). Current losses from this insect continue at a rate of from \$100 million to \$200 million per year. With the possible exception of soybeans, all our major field crops frequently grown in monoculture have been subjected to insect epidemics serious enough to be regarded as at least a local disaster. These losses amounted to \$6.8 billion each year from 1951 to 1960 (National Academy of Sciences, 1969).

While losses from weeds in field and horticultural crops in the United States are not as spectacular as from diseases and insects, they are large. Between 1951 and 1960 American farmers spent more than \$2.5 billion annually in the control of weeds (National Academy of Sciences, 1968). Weed losses in the U.S. are estimated at \$5 billion per year (Shaw and Lovvorn, 1953). The ecology of weed populations is closely associated with the practice of temporal monoculture in crops. Continuous cropping to one species tends to favor the development of weed pests particularly troublesome to that crop (Crafts and Robbins, 1962).

A monoculture is more susceptible to climatic hazards of drought, hail, frost, and hot winds than a diversified agriculture. Even in the humid and irrigated areas of the United States, the variability in temperatures and precipitation is important in planning cropping systems. We doubt, however, that weather hazards will be a deciding factor either for or against monoculture anywhere in the United States, except perhaps in the Great Plains. Thornthwaite (1941) suggested that this large, semiarid area be restored to grazing land with a relatively few large farm units. Although this may also be regarded as monoculture, it is a stable type dependent on a number of forage species.

In addition to being relatively unstable agricultural ecosystems, monocultures are also vulnerable to disaster from social and economic disruptions. Transportation failure resulting from strikes at the time of harvest can cause local, national, and international problems, but most particularly problems for the individual farmer. If the farmer is dependent on a single cash crop and is unable to market that product, the result may be bankruptcy if the crop cannot be stored. Recent boycotts were most effective when large acreages of perishable fruits and vegetables were involved.

Although monocultural systems of crop production may be hazardous and unstable as ecosystems, they generally lead to highly efficient types of production. The report of the Workshop on Global Ecological Problem states, "The most impressive feature of industrial agriculture is its high biological productivity" (Institute of Ecology, 1971). In our present social, economic, and political milieu, intensively managed ecosystems with high energy requirements will undoubtedly continue to flourish as long as they are profitable and the resources are available. Indeed, pressures from the rapidly increasing population of the world may demand such management intensity long after it is no longer profitable.

Effects of High Energy Consumption and Mechanization

Modern agriculture is characterized by high inputs of energy in a variety of forms. This is associated with the substitution of capital for labor, and machinery for horse and mule power that has occurred over the past few decades. Mechanization has encouraged and made possible the trend to larger farms, although many farms that have not increased in size during this time frame are highly mechanized.

Mechanization and the accompanying trend to larger farms has contributed, along with other factors, to the growth of monocultural systems in agriculture. Similarly, the trend to monoculture has made the use of specialized machinery more efficient to the farm enterprise. The separate effects of mechanization and monoculture as related to high energy consumption in agriculture are difficult to identify.

Increased energy consumption is represented by the on-farm dependency on fossil fuels and electrical energy. Off-farm energy inputs required in such things as the manufacture of machinery, chemical fertilizers, and pesticides are represented also. There can be little doubt that energy expended per acre has increased markedly in the past 30 to 40 years. On this basis, it appears that agriculture has become less efficient.

Yet, reckoned against this is the release of much human energy that has migrated to urban areas where it sustains other industries. However, not all of this migration represents a societal gain. Moreover, labor that has remained in agriculture is better paid for less physical effort.

Replacement of horse and mule power by machines released some 80 million acres of agricultural land from production of feed for these animals. This land has been converted to crops for direct sale, for feeding to income-producing livestock, or to the acreage reserve. During the past 40 years, agriculture has doubled total production while at the same time using less land. By using conventional measures, agriculture has become more efficient in use of all resources in converting energy from forms unusable as food by man to forms that sustain human life. The trend to monoculture is important in this increased production efficiency.

On the other hand, the increased use of energy in the mechanization of agriculture contains some inherent dangers. Consumption of fossil fuel, directly as a fuel for farm machines such as tractors and trucks, and indirectly in the manufacture of production inputs, has risen sharply. In a real sense, modern monocultural agriculture is dependent on that exhaustible resource. This could also be true if agriculture were highly mechanized without monoculture. Disruptions in foreign supplies or reduction in total supply of fossil fuel probably would materially increase energy costs and, thus, could have a serious impact on production cost efficiency of food and fiber. To this extent agriculture is vulnerable. Such an occurrence would have a similar impact on all segments of the U.S. economy, which are interdependent to an enormous degree. An awareness of this vulnerability is not often encountered.

Effects on Wildlife

The development of agriculture, with its spatial patterns, affects in various ways the vertebrate fauna of the area, modifying both its quantity and its qualitative composition. These changes are likely to affect all groups of vertebrates, including fish that inhabit waters receiving runoff from the agricultural lands. The species in which man has the most direct interest are those on which he himself acts as predator—the game animals. The discussion below, however, is broader in scope, and considers wildlife in general—including unwelcome species as well as those that are active agents in the biological control of agricultural pests.

A general rule is that the diversity of each trophic level depends on that of lower trophic levels. Each new plant species added to an area of vegetation provides additional niches for the herbivores that may feed on it partly or exclusively, and for animals that may use it in other ways (for example, birds, for nesting). Each new herbivore provides an additional choice of prey for carnivores, thus increasing the potential diversity of the carnivore population. This argument might lead one to suppose that there would be an exponential increase in diversity as one ascends the trophic pyramid.

But this tendency is to some extent countered by a decrease in biomass and numbers along the same sequence. Breeding requirements, and, in larger areas, the need for a certain genetic diversity to sustain a viable population, put a lower limit to the population density of a species, and hence an upper limit to the diversity within a given total population of large animals in the higher trophic categories. But there is no doubt that the relation of the diversity at each trophic level to that of the levels below it is positive.

Though exceptions may occur—as in systems of shifting cultivation in the tropics—most agricultural landscapes are likely to have less floristic diversity than the natural landscapes they replace. The number of crop species useful to man that can be grown successfully in a particular area is usually much less than the number of species of similar abundance in the natural vegetation. The diversity of adventive plants in cropland is likely to be reduced by directly adverse factors, such as cultivations and herbicides that do not affect the minor constituents of the native vegetation. In consequence, an agricultural landscape—even one of mixed cropping—has a larger proportion of the biomass concentrated in a small number of species than is usual in natural plant communities. Thus, the niche diversity for herbivores—and, *a fortiori*, for carnivores—is much reduced.

The reduced *floristic* diversity of a landscape devoted to mixed agriculture is countered, to some extent, by increased *spatial* diversity. Whereas the natural landscape may have been covered for miles by a woodland that despite its local patchiness was statistically uniform, the farmer has divided it into fields devoted at any given time to different crops. The interfaces among different types of vegetation are thus much more extensive. Some animals find their optimal habitat at such interfaces (Leopold, 1933) because they need the combination of two types of habitat in proximity for different types of activity by night and day, for foraging and reproducing, for protection from predators, and as a feeding area.

Jack rabbits in the Great Basin divide their time between reseeded areas that provide them with an abundance of favored food and native sagebrush that gives them better daytime protection. The sharptail grouse in Wisconsin is largely dependent on the "rough edge" of bush and young trees between the farmland and the forest (Hamerstrom and others, 1952). Damage by deer to forest plantations in England is far greater when plantings are in the form of strips, with a large periphery/area ratio (Prior, 1968). The hedgerows that border the fields of southern England, also, are a haven for wildlife (Elton, 1958) so that their population of birds is probably greater than that of the extensive woodlands they represent. The decline of quail in Wisconsin was closely associated with decrease in the hedgerow habitat (Kabat and Thompson, 1963).

On the other hand, some larger animals—particularly herbivorous mammals—require a fairly large continuous area of suitable habitat to survive.

The fragmentation of the landscape associated with small-scale mixed agriculture may have adverse effects on such animals while at the same time favoring those species which benefit from the availability of two or more different habitat types in proximity.

Mixed agriculture, then, may on balance have little effect on the diversity of wildlife. The same does not apply to monoculture in its more extreme forms. Here the greatly reduced niche diversity, coupled with spatial homogeneity greater than that of most natural vegetation, cannot but reduce the specific diversity of wildlife.

Agriculture will have marked selective effects on wildlife species present even if, because of spatial heterogeneity, it does not reduce wildlife diversity. Each species has its optimum set of foods and habitats, and those offered by a particular crop, or group of contiguous crops, will not be the same as those offered by any part of the natural landscape. The foods offered by crops and their associated weeds may be better than those from the native plants, but they will certainly be different. Consequently, selective pressures will be exerted which differ from those operating before the establishment of agriculture, and a new set of species will become prominent.

As an inverse example, the numbers of partridge increased greatly when wheatlands were allowed to revert to native vegetation. Some examples may be drawn, too, from range improvement operations in the Great Basin, where large areas of native sagebrush vegetation have been destroyed by chaining or spraying, as a preliminary to reseeding with crested wheatgrass. The effects have practically eliminated the sage grouse and after a temporary increase in antelope populations during a short period of forb dominance their numbers abruptly diminished as the grasses took over. Similarly, large changes in grouse populations have been reported in Scotland following the burning of heather (Miller and others, 1970).

Changes in wildlife populations occasioned by agricultural development are not necessarily drawbacks, on balance, from the human point of view. Perhaps the newly abundant species will be of interest to hunters. Perhaps they will be aesthetically attractive songbirds.

In monoculture, as in mixed agriculture, selective pressures will be changed. They will be more rigorous because of the reduced niche diversity. Again, it may be that the favored species are ones that, for one reason or another, are advantageous to man. However, because those favored by selection are relatively few, the chance that desirable species will be included is rather small.

Sometimes the wildlife favored by a cropping system has a directly adverse effect on the farmer's objective. The pheasant may pull newly sprouted crops. The kangaroo in Australia may find the wheat fields a comfortable resting place. When this happens, the farmer may find himself obliged to take active measures against the wildlife he has inadvertently fostered by destroying them, not as a sport but as a chore. In this respect, wildlife is no different from insect pests favored by cropping systems. The problem is more likely to arise in monoculture as a result of the reduced crop diversity, extending to the predators that otherwise might be able to hold the undesirable species in check.

If a wildlife species has a direct adverse effect on crop plants, even though it has not been increased in numbers as a result of cropping policy, the farmer will do his best to reduce the population of that species by any practicable means. Increased homogeneity of cropping may make such action more desirable, and may change the spectrum of practicable action. Steps that are neither practicable nor worthwhile for protecting a crop of cherries on a single garden tree may become essential for an orchard covering tens of acres.

Other effects of agricultural practices on wildlife are indirect. One such effect that has attained considerable prominence is the result of use of pesticides (Moore, 1966, 1967; Rudd, 1964). Chemical pesticides directed against insects will also be assimilated by wildlife—either through consumption of the insects themselves, through eating plant parts bearing residues, or through runoff water entering creeks and lakes where it becomes available to the fish populations (Johnson, 1968). It is well known that some of these substances tend to become more concentrated in higher trophic levels. Many are as toxic to vertebrates as to the insect targets.

As shown elsewhere, the use of agricultural chemicals and the development of intensive agriculture tend to increase together. Moreover, in monoculture the range of chemicals used over an area during a particular period tends to become narrower, so that the exposure of wildlife to particular chemicals will increase more than in proportion to the total chemical usage. Large areas devoted to single crops also encourage the use of different methods for applying pesticides—notably aerial spraying, which may affect appreciable areas outside those covered by the crop, thus increasing wildlife exposure.

Agricultural practices, apart from pesticide use, often lead to important modifications in aquatic environments that will affect both the fish populations and those birds and mammals requiring, or favored by, a riparian habitat. Agricultural development, particularly as it tends to monoculture, is often associated with drainage of small lakes and ponds, canalization of streams, and the clearing of their banks. The runoff from agricultural land following storms is often increased in volume compared with runoff from native vegetation and may lead to periodic floods that scour the watercourse. Such situations are notorious in India, for instance. On the other hand, water use for irrigation—particularly in arid regions—may reduce streamflow to a trickle.

The increased runoff from agricultural land during storms generally carries a heavier load of sediment. The great fluctuation in water volume, together with the quantity of sediment under these conditions, makes the watercourse a much less satisfactory habitat for fish (Etnier, 1972).

Moreover, runoff from heavily fertilized agricultural land will carry an increased content of nutrients, particularly nitrogen compounds. It is shown elsewhere that the use of chemical fertilizers has tended to increase as monoculture developed. Nutrients added to natural waters lead to eutrophication, with increased development of algae, changes in the specific structure of higher trophic levels (often favoring coarser fish species less attractive to anglers), and, in the extreme, killing of higher animals by anoxia when the decomposition of the algal mat exceeds photosynthesis (National Academy of Sciences, 1969).

Not only water is polluted by modern agriculture. Agricultural tractors and other machinery, commonly used more intensively as agriculture tends to monoculture, contribute to atmospheric pollution. There is little doubt that atmospheric pollution has its effects on wildlife, as well as on man, but this has been little documented.

Other minor effects of agricultural homogeneity may be mediated by the resulting changes in the human population. Under monoculture, the human population tends to be sparser than under mixed agriculture, has a different demographic composition, and differs in outlook, recreational habits, and the like. In consequence, one may expect the hunting and fishing pressure on wildlife from the rural population to change, and in general to diminish as progress towards monoculture proceeds. On the other hand, the population that has migrated to the towns will continue to look to the more accessible parts of the surrounding countryside for this type of recreation. Thus, the net effect may be a change in spatial distribution of hunting and fishing activities, with perhaps a change in qualitative character, rather than in overall quantity.

Sociological Effects

Concentration of one or two crops in an area has some obvious advantages. It permits specialization of labor, suppliers of services and production inputs, and processors of commodities. Knowledge of improved techniques, superior varieties, and so forth is disseminated rapidly. Sometimes seasonal demands for labor can be coordinated between two crops or with nonagricultural activity in the area.

However, labor demands of monocultural agriculture often are highly peaked during short periods of the year and during the rest of the year very little labor is required. For many crops the seasonal work load is insufficient to support a worker over the entire year and the growers use migrant labor. The problem of the migrant worker is well known: poverty, rootlessness, and a lack of education for the children who will rarely obtain the skills required for a better job.

Specialization of an area also can make it more vulnerable by tying its fortunes to one commodity. For example, wheat-growing communities were devastated during the 1930's by a combination of drought and low wheat prices.

Today, most of the sociological imbalance associated with monoculture has been more directly tied to mechanization. While monoculture does not cause mechanization, it facilitates it to a high degree. At least in most situations, mechanization requires relatively large fields and may also require a reservoir of operating expertise, complementary technology in processing, and large scale suppliers of basic equipment, parts, and service. These conditions usually point to specialization of an area and some degree of monoculture.

The sociological imbalance of monoculture has been amplified by the type of technology adopted. While labor's share of the total national income has stabilized, mechanization rapidly depressed labor's share of agricultural income. In 1970, this share ranged from a high of 44 percent in the Lake States to a low of 21 percent in the Corn Belt. In almost every region, labor's share in agricultural income was about half what it was in 1950.

Mechanization of cotton production and associated changes in technology has occurred at great cost in dislocation of people. In 1950, labor input on cotton in the Appalachian, Southeast, Delta, and Southern Plain States totaled 1,150 million man-hours. By 1968, this was down to 235 million, a reduction of 80 percent. During the same period, cotton production in that area increased from 8.1 to 8.3 million bales. Acreage decreased by 45 percent (Gavett, 1970).

Over 900,000 workers were displaced by changes in cotton production technology. Including dependents, 2.5 million to 3.0 million people were directly affected. Most of these people left the South—at least the rural areas of the South—and migrated to cities, where many did not have the skills necessary to find profitable employment.

The Corn Belt and Northern Plains[1] saw substantial shifts in population between 1960 and 1970 as farms became larger and machinery was substituted for labor. Census of Population data show that in the Corn Belt 212 counties in 496 had population decreases totaling 356,000 people. The change in the Northern Plains was even more spectacular. Some 242 in 319 counties showed a decrease totaling 236,000 persons. While this change was not as traumatic as that of the Southern cotton belt, many small towns were depopulated and businesses, schools, and churches were closed or consolidated.

A problem similar to that resulting from cotton mechanization appears to be in the offing for flue-cured tobacco. Mechanical harvesters have been developed that will harvest prime flue-cured tobacco with only a fraction of the labor used in conventional hand harvesting. As yet, virtually no tobacco has been machine harvested. A delay such as this in adoption of a new technology is not unusual. The first successful cotton picker was built in 1941. Potato harvesters were developed between 1940 and 1945. Today, over 95 percent of cotton and about 90 percent of potatoes are harvested mechanically. Cherry shakers and tomato harvesters developed during a period of rapidly rising

[1]The Northern Plains comprises North and South Dakota, Nebraska, and Kansas.

wages and disruption of the labor supply caused by termination of the Bracero program were more rapidly adopted.

In 1968, flue-cured tobacco production in five States[2] was distributed among 194,000 farms holding a total of 608,000 acres of allotment—an average of slightly over 3 acres per farm. Use of the harvester is optimized at about 40 acres. Complete mechanization of production could mean a reduction in farm operators of up to 180,000, which, with seasonal workers and dependents could directly affect about 1.5 million people (Gavett, 1970).

Farm-to-city migration has overimpacted the urban areas that have to absorb these people. Tax rates and welfare roles increase. Other types of services become more expensive as urban population rises. For instance, septic tanks may provide sufficient sewage services for a small town, but as the population increases a more complex treatment plant is needed. The Nobel-prize winning economist, Simon Kuznets, estimates that these hidden costs of urbanization amount to more than 10 percent of our Gross National Product (Kuznets, 1971). Yet he ignores many "deprivations and discomforts" of urbanization "for which no economic price tag seems appropriate." He adds, "these may range from such obvious and distasteful consequences of economic growth as air and water pollution, to more subtle effects of urban civilization represented by the difficulties of maintaining privacy and escaping from the vulgarities of mass media and from irrational and domestic violence." These costs represent some of the economic consequences of the sociological imbalances resulting from the farm exodus.

In summary, monoculture is not a direct cause of mechanization. The two, however, are associated and reinforce each other. Mechanization makes possible large-scale production of a crop, usually requiring large fields and a concentration of acreage to be profitable.

Historically, monoculture in the U.S. has made areas dependent upon certain selected crops as a source of employment. Rapid mechanization has on occasion necessitated readjustments at great personal cost to a large number of people. Extensive migration has left many rural communities without a population base adequate to support educational, medical, and other social services. At the same time, urban communities have had to absorb large numbers of immigrants, some of whom are not adequately trained for the types of employment available.

[2] North Carolina, South Carolina, Virginia, Georgia, and Florida.

Increase in Fertilizer Use

During the past two decades, substantial increases have occurred in the application of plant nutrients derived from commercial sources (Tenn. Valley Auth., 1971). Two general factors are responsible for this increase. The 20-year period brought an increase in the physical yield response to fertilizer. New varieties and cultural practices in general, interacted positively with the response to fertilizer, thus increasing the incentive for higher application rates. The second factor has been the drop in the cost of plant nutrients. According to data prepared by the Tennessee Valley Authority, the price of plant nutrients decreased by 50 percent while the cost of farm real estate and farm wage rates rose about 200 percent. The price of nitrogen fertilizer relative to the price of feed grains has dropped substantially also.

Partly because fertilizer application rates have increased, the need for cropland in the U.S. has actually decreased. (See table 1, ch. 2.) In 1950 about 377 million acres of land were used for crop production including summer fallow and crop failure. By 1966 only 331 million acres were in crops, and cropland needs have been only slightly higher since then. These acreages were adequate even though export markets became increasingly important in the 1960's after a decline in the early 1950's. In short, the land-saving contribution of fertilizer must be recognized as an important development in agricultural production during the last two decades.

The relationship between increased fertilizer use and spatial heterogeneity depends, in part, on the unit of analysis. Viewed on a national scale and considering only two uses—cropland noncropland—increased fertilizer use contributed to *increased* spatial heterogeneity through a reduction in the cropland requirements. Of course, the mix among crops within the cropland and the land-use patterns within noncropland are aspects of spatial heterogeneity that must also be considered.

As we move to a smaller unit of analysis, such as the farm unit, the county, and the region, the consequences of increased use of fertilizers depend on differences among the areas in yield response to fertilizer and the economic competition among crops within and between regions. At the regional level (table 2, ch. 2) from 1944 to 1964 acreages in cropland decreased 26.8 million acres. However, four of the 10 regions had increases in cropland. One of these regions was the Corn Belt. In this region diversification of crops dropped largely because of increases in the acreage of corn and soybeans. The increase in corn acreage resulted in part from the drop in the relative price of nitrogen fertilizer, thus improving the competitive position of corn in relation to legumes in the rotation. The real cost of nitrogen produced by legumes was not low enough to justify their position in the rotation. Here, the increased use of commercial fertilizer contributed to a *decrease* in diversity.

Today many people are greatly concerned over the possible damage to the environment by use of high levels of fertilizer. While this is not an issue of spatial heterogeneity or crop diversity per se, restrictions on fertilizer would likely cause at least some increases in the use of land for crops. Although other input substitutes are available besides land for maintaining needed levels of output, restrictions on use of fertilizer are most likely to be followed by release of set-aside acreages for crop production than by substituting other nonland inputs. This expected increase in cropland would, at least at the national and regional scale, decrease spatial heterogeneity in that cropland would increase and noncropland would decrease. Finally, such increases in cropland use might also cause increases in soil loss and sedimentation as land less suited for cultivation is brought into use.

Separation of Production and Utilization

Western economists from Adam Smith on considered division of labor as a prime source, if not the fountainhead, of the aggregate increases in productivity that spell economic development. They pointed to three reasons for increased productivity: (1) Workers waste less time shifting from job to job; (2) workers can become more skilled in their individual specialties; and (3) equipment can be used more nearly continuously. A similar principle was applied to regions and nations, labeled as the law of comparative advantage.

This principle provides the basic economic argument for monoculture. A farm can specialize. The manager and workers can develop expertise in a specific crop. Machinery can be specifically adapted as can farm layout and buildings. Crops are grown in areas where they are biologically and ecologically best suited and provide highest return. There are advantages also to areal specialization. Suppliers of farm inputs need to stock fewer items of machinery, parts, fertilizers, and chemicals, and they can have more dependable stocks of those items that are needed. Handlers and processors of farm products can develop greater capacity for specialized products and take advantage of economies of scale. These economic factors have been decisive in the trend to monoculture.

However, to the extent that regions specialize in particular crops, production and utilization are separated. The degree of separation is influenced by many factors, especially population centralization. Concentrating wheat production in the Great Plains or vegetables in California or Florida, for example, means longer hauls to areas of consumption. Specialization usually has resulted in production of feed grains and concentration of feeding operations, particularly for poultry and beef, in separate enterprises that sometimes are remote. This separation requires transportation of the bulky grain and concentration of manure at the site of feeding operations. On a mixed farm, livestock provide manure, crop residues help maintain livestock, and wastes are returned to the land. Where livestock are concentrated in large feeding operations, disposition of animal wastes becomes a major problem, crop residues are burned or incorporated into the soil rather than used as animal feed and bedding, and the crop grower depends upon chemical fertilizers instead of manures and other wastes.

Physical separation of production and consumption areas is one of a complex of factors that has required development of technology and physical facilities into a marketing system capable of processing, transporting, and marketing adequately attractive and nutritious food on a year-round basis, over long distances, and at prices most consumers find acceptable. Conspicuous examples of the capabilities of this system are the ready availability of large quantities of fresh fruits and vegetables on a nearly year-round basis throughout all geographical parts of the country, regardless of local production capabilities. The marketing system that has evolved to service American food producers and consumers requires the use of many food preservatives and additives for some products. Some of these are now being questioned regarding food safety.

Also inherent in the present production and marketing system is the accumulation of large volumes of wastes that often have been flushed to the sea through sewage-disposal systems. Ideally, wastes should be recycled through the production system. The extreme separation of production and consumption makes this difficult.

Monoculture is involved in the separation of production and consumption of agricultural products, but it has not caused that separation. A change to more spatial heterogeneity probably would not affect this materially because of the established patterns of population distribution. Opportunity for change appears greatest in decentralization of livestock feeding. But even here established patterns are very strong.

Aesthetic Monotony

It has been stated that "Beauty is in the eye of the beholder." What is aesthetically pleasing to one person may be more or less so to the next. Variety and novelty seem to be characteristic of landscapes that are pleasing to most people.

Contact with nature brings a measure of contentment to many people and the need for such contact becomes more apparent as our population becomes more and more concentrated in the megalopolis. According to Watt (1972), "We have evolved over a very long period, so that our minds can cope handily with a certain rate of incoming sensory stimuli. We find the stimuli rate we can cope with in nature because we evolved there." The Menninger clinic employs a horticultural therapist in its Memorial Hospital, and both Michigan State University and Kansas State University offer degrees in this field (McCondless, 1967). The need for contact with nature seems well recognized.

Monocultures in agriculture have been criticized for being aesthetically monotonous. They probably are monotonous to people who have only occasional contact with them. Yet, the resident observes a great variety by differences in topography, exposure, time of day, crop species, farm pattern, and color. It seems unlikely that people engaged in pursuits related to monocultural agriculture suffer very much from lack of interesting contact with nature although the possibility is recognized. Only 10 to 12 percent of the counties in the United States have half or more of their land area in cultivated crops (fig. 1). These counties are concentrated in certain areas each with its characteristic complex of crop species. For the most part, these areas are not adjacent to our large population concentrations. Rather, areas of greatest landscape diversity are the ones located near areas of dense population.

Thus, on the national scale aesthetic monotony seems no more characteristic of monocultural agriculture than of other parts of the national landscape. We would not view aesthetic monotony as a particularly objectionable feature of agriculture except perhaps in relatively few areas of the country where monoculture is most intense and topographic variations are minimal.

Lack of Flexibility

A move toward monoculture in agriculture frequently is accompanied by a degree of loss in the flexibility of the farm operator. Commitment of resources to specialized production of a single commodity often limits potentials for shifting to production of other commodities in response to changing market demands or other factors.

Monoculture fosters, or sometimes is fostered by, the creation of a web of interdependent, related businesses. The agricultural chemical producer, the farm implement dealer, the storage operator, the transporter of goods, the processor of agricultural produce, distributors, retailers, and labor are as much a part of the web as the producers themselves. Their interdependence often inhibits any sector of the agricultural industry from making rapid innovations in methods, equipment, or materials.

The limitation of flexibility has been accepted by the participants as a worthwhile trade-off for increasing average income. But the commitment of agriculture and related business to a single commodity, together with the reduced flexibility contingent with that commitment, renders that sphere of activity extremely vulnerable to outside decisions. Such decisions may have serious effects. Competition from other commodities may result in a lowered market demand and consequently in decreased rather than increased income. In such instances, communities may experience a severe economic recession.

Political Implications of Monocultures

Much legislation and many governmental programs that benefit or restrict certain groups of the governed people result from the persuasive effects such groups have upon legislators and governmental administrators. Historically, agricultural groups have been among the most successful groups in this activity.

The nature of the agricultural groups and their persuasive efforts have changed over the years, paralleling the changes in agriculture. Trends from mixed farming toward larger farms, mechanization, and monoculture produced parallel changes in political interests on the part of farmers. These interests were often reinforced by management of the associated agribusiness sector that developed in association with these trends.

The concentration of agriculture in a geographic area on a single crop, or a very few crops, means that legislators from that region will be subject to more intense and direct pressure than if the cropping pattern were more heterogeneous. Such pressures may reflect very well the immediate interests of the farmers who produce that particular crop. At the same time, they might not be in the interest of the public welfare generally.

Similarly, pressures can be brought on administrators of public research agencies to allocate more and more resources to the monocultural commodity at the expense of other commodities. On the other hand, such interest groups often can be very instrumental in securing additional resources for research from legislative bodies or from their own commodity organizations.

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5. ALTERNATIVES AND MODIFICATIONS

A feature of modern agriculture is its high biological productivity. This results from the economic incentive for entrepreneurs to combine the inputs of managerial ability, land, and capital in the form of physical plant, machinery, fertilizer, pesticides, and energy into a production system that maximizes return to the enterprise.

Management decisions are influenced by external forces such as markets, input costs, and other considerations associated with the web of interrelated activity that is the American economic system. Only recently has the environmental consequence of a decision become an important consideration in agriculture, or in any other industry for that matter. Furthermore, concern has been voiced regarding agriculture's ability to sustain itself if high inputs of energy, fertilizer, and pesticides continue. The Institute of Ecology in its 1971 report "Man in the Living Environment," stated, "Our general conclusions are that the successful maintenance of man's productive systems will depend on an effective accounting and controlling of the major exchanges of energy and nutrients in ecosystems and in the maintaining or creating spatial, temporal, and species diversity within such systems."

This report points out that stability in natural ecosystems results from diversity among and within species and that these systems, for the most part, have low energy flow. From this it is reasoned that modern agricultural systems are naturally quite unstable because of lack of diversity and can be maintained only through high inputs of auxiliary energy in various forms, many of which have undesirable side effects on the environment. The report indicates further that the need for high usage of certain inputs could be reduced by greater spatial heterogeneity in agricultural landscapes.

The biological principles operative in natural ecosystems have evolved through eons of time. In that evolution, the selection pressures were in the direction of stability of the systems and their ability to tolerate the most severe environmental stresses occurring over a period of time. Population fluctuations in such systems are often considerable. Finally, their capability to sustain man usually is very low.

Man found early in his history that he could select plants from wild populations that were above average in ability to produce products he could use and also that they responded to improved culture, especially production in more or less pure stands. Gradually, population pressures demanded more food production; more land was cultivated and more intensive selection and cultural practices were employed. This process then accelerated until modern monocultural agriculture was developed. Modern agriculture employs high levels of production inputs that abet biologically efficient plants in the conversion of energy unusable by man into energy that man can use. Rates of input are usually governed by economic forces. Ecosystems that are stable only with those inputs are that way by design.

The application to cultivated ecosystems of biological principles operative in natural ecosystems must be made cautiously. For example, because only a relatively few number of crop species are grown in a region, and because, in many areas, economic pressures prevent allocation of good land to less unproductive purposes, the application of the concept of spatial heterogeneity might have little effect on pest populations and on the need for their control. The web of biological interactions may be too limited to effect biological control of pests to levels below economic importance. Coadaptation of hosts and pests may be impossible in such ecosystems. We need to know whether this is true in any or all cropping situations. Perhaps there are spatial patterns that could be biologically effective and economically viable. If so, their use should be strongly advocated.

Considering the economic mechanics in this country and the life styles and food consumption habits of its people, the Task Force sees little likelihood of possible shifts from intensive agriculture to less intensive forms. But we must not be content with the present situation. Within the constraints of adequate food, feed, and fiber production at a reasonable price to consumers. we should strive to correct the shortcomings of monocultural agriculture, particularly those that result in environmental degradation in its broadest sense and those that may have potential for threatening survival of agriculture itself. Changes that can be made will necessarily involve tradeoffs among technical feasibility, economic viability, social acceptability, and ecological stability.

Genetic Diversity and Pest Management

As man domesticated plants and animals and incorporated them into intensive agricultural production systems, the natural balances between these domesticated species and their parasites, which permitted both host and parasite to survive, oftentimes were upset so severely as to cause almost complete decimation of the host over areas as large as a continent. For example, stem rust *(Puccinia graminis tritici)* of wheat and late *blight (Phytophthora infestans)* of potato have been so severe in certain years and in certain countries that they caused famine and great sociological upheavals (Wood, 1953).

The development of monocultural crop production systems, whereby vast areas of a country or continent are planted to a uniform cultivar of a crop species, or the same cultivar of a crop species is planted on the same land area year after year, has greatly intensified parasite management problems. For low-income crops, plant scientists have bred natural pest resistance into cultivars, but this method of control tends to be ephemeral for many plant pests, such as the rust diseases *(Puccinia* spp.) of cereal grains, because the pest is genetically variable for virulence loci. However, where the economics are favorable, plant scientists have attempted to control plant pests by use of pesticides. Lately, environmentalists and others have expressed concern that these pesticides, especially the persistent ones, may contaminate the environment to the point of being directly harmful to wildlife and eventually to man. The public tends to blame monocultural crop production systems for pesticide pollution problems.

Because monocultural systems probably are completely unavoidable, scientists should devise effective methods of pest management for use in monocultural systems that are effective without polluting the environment. Pest management within intensive or monocultural crop production systems, with or without limited pesticide use, may be possible through the following technologies:

1. Varieties resistant to disease and insects have proved effective in reducing crop losses. Sizable breeding efforts are being directed to development of such varieties. Resistant varieties of most important crop species have resulted and many opportunities exist for further advancements in this direction.

2. Increased genetic diversity can provide for multiple resistance to known diseases, insects, and nematodes. It can also provide a broad genetic base that would materially reduce vulnerability to new pests. Such diversity could contribute to reduced dependency on many pesticides. In short, increased genetic diversity in cultivated crops would simulate, to a limited degree at least, the genetic diversity that, in part, confers stability on natural ecosystems.

Often, resistant varieties have been short lived because a biotype of the parasite evolved that could attack the new variety. Pest management can be improved by replacing pure-line with multiline varieties (Browning and Frey, 1969). Growing multiline varieties is entirely compatible with monocultural crop production systems.

This method can be used to increase genetic diversity in a self-pollinated feed grain crop where grain-quality standards are of minor importance. In many crops, quality standards greatly complicate increasing the genetic diversity. Nevertheless, genetic diversity is such a powerful potential tool for successful pest management that it should be an important objective in most crop breeding programs.

A vast monoculture production area for a crop species can be subdivided into smaller epidemiological units by appropriate deployment of sets of host resistance genes (Browning and others, 1969). Such a research and gene deployment agreement has been put into practice for rust resistance genes of oats by several experiment stations in the Puccinia Path of North America. This represents a system that is completely compatible with continued use of monoculture and having the potential of reducing the opportunity for continental epidemics.

3. Various methods of pest management offer additional opportunities for improved pest control with minimal environmental effects.

- *Better utilization of native parasites and predators.*—Indigenous pest parasites and predators can be encouraged by various means. Artificial food materials sprayed in fields will aid in maintaining these beneficial insects even when pest populations are low (Hagen and others, 1970). Strip harvesting of alfalfa hay also has been effective (Stern and others, 1964; van den Bosch and others, 1967).

- *Trap crops.*—Some pest species have a great preference for certain crops over others. Lygus bugs are the "key" pest of cotton in the San Joaquin Valley, Calif. However, if lygus bugs are given a choice, they will feed on alfalfa instead of cotton. Alfalfa acts as an attractant host plant. The interplanting of 20-foot-wide strips of alfalfa with every 300 to 500 feet of cotton can greatly reduce the number of bugs in the cotton (Stern, 1969). This concept is directly related to environmental diversity.

• *Genetic methods.*—The genetic technique offers great possibilities for conquering many of our most important pests. It is highly sophisticated and requires well-trained, competent, and imaginative scientists in several scientific disciplines. The screwworm is a classic example (LaChance and others, 1967). Several other pilot programs are underway, including sterilization of the boll weevil, pink bollworm, codling moth, and others.

Another genetic method is to introduce and spread lethal genes in pest populations. For example, the USDA cotton research laboratory at Phoenix, Ariz., has a laboratory colony of the pink bollworm that carries a lethal gene at temperatures above 85° F. If large numbers of these pests could be introduced into the environment in early spring, they could spread this lethal gene and when temperatures rise above 85° F., as they do in almost all areas where the pink bollworm is found, the resident bollworm population would die.

• *Introduction of parasites, predators, and diseases.*—Many of these are being introduced for control of exotic insect pests and for weed control. There are many examples of successful introduction of this type and emphasis now is placed on this research.

• *Insect pathogens.*—Research is being conducted in many areas on bacteria and viruses that attack insects. Recent programs include studies on viruses that attack the corn earworm, codling moth, cabbage looper, beet armyworm, gypsy moth, and others (Falcon, 1971).

• *Self-regulating mechanisms.*—Some insect species regulate their own numbers, thus preventing overcrowding where all might die. For example, the oldest maturing larvae of some mosquito species release a chemical into the water that inhibits the growth of younger larvae of the same species. This chemical is a potential tool for use in preventing the breeding of mosquitoes.

• *Insect hormones.*—Recently, much emphasis has been placed on insect hormone research. The growth and development of an insect is controlled by hormones. Identification of these hormones and their administration onto insects at the "wrong" time of insect development may lead to control.

• *General environmental manipulation.*—Cultural control techniques have been used by entomologists through the years to create situations disadvantageous to pest insects. This alternative method of pest control is now receiving new emphasis.

• *Trapping, attractants, and repellents.*—Pheromones are sexual scents given off by certain insects when they are ready to mate. A male moth may not be able to find a female if he cannot detect her pheromone. This behavior is so strong that a sensitive means of monitoring the population densities and the spread of insect infestations has been based on a determination of the number of males caught in pheromone traps. Investigators are experimenting with the concept of spreading pheromone odors over fields so the male insects cannot find the females that are releasing the same pheromone.

• *Pesticides.*—Pesticides are not likely to be abandoned as a tool in pest management. However, their use needs to be better integrated with other methods of control into effective systems having minimal detrimental environmental effects. More effective and target-specific pesticides that can be used safely should be developed.

Diversification and Crop Rotation

The general pattern of agricultural development has been one of intensive row crop production on natural prairie grasslands, dependence on row crops and grassland in areas formerly occupied by forests, and the maintenance of extensive grazing cultures on the drier steppes and desert range. Although monoculture is characteristic of many crop production systems, these systems vary in degree and extent of crop diversity achieved through crop rotation.

As mentioned in chapter 3, crop rotations received emphasis in programs to improve soil fertility and soil structure and to reduce soil and water losses. In a general way, such rotations are beneficial in spreading risks and in conserving soil and water resources (Hanson, 1972; Jacks, 1944; Wadleigh and others, 1972). However, some soil classes cannot or should not be cultivated regardless of diversity introduced through crop rotation (Hanson, 1972; Mossey and others, 1953; Wadleigh and others, 1972). Row crop production on these erodible sites might involve new technology, such as minimum tillage and sod seeding, but cannot proceed through the simple expedient of imposing classical crop rotation schemes.

In the wet tropics, crop rotation may not be practical on sloping land where cultivation, even at infrequent intervals, results in severe erosion. In these areas, optimal land utilization for agricultural purposes will be permanent plantations of such long-term crops as cocoa, coconuts, rubber, tea, and coffee, with the addition of sound soil erosion safeguards.

In humid temperate regions, losses from many weeds, diseases, insects, and nematodes can be reduced by use of specific crop rotations. Rotations break the normal life cycle of many pests and thus reduce the incidence of a particular weed, disease, or insect pest. For example, rotation of crops within a spatial monocultural crop production system can aid in reducing epidemics of sedentary pests. For several decades about 30 percent of the acreage of Iowa has been planted to corn. Corn rootworm did not become a serious pest in reducing corn yields until the planting pattern changed to a temporal monoculture in which corn was planted continuously on areas of level land. With continuous corn, the use of pesticides to control rootworm became a rather standard practice. By growing corn in only 1 of 3 or 2 of 4 years on the same land area, the population level of the corn rootworm was maintained at levels that did not cause serious damage. This is an example of a situation where a change in cropping pattern within a spatial monoculture could provide adequate pest control without the use of pesticides.

There are at least four major factors that must be considered in evaluating the role of crop rotation in increasing diversity and in reducing hazards to crop production.

(1) Size and spatial relationships within a given farming unit must be considered as well as those that prevail at a higher level of organization. Thus, pest problems could differ appreciably with a four-crop rotation where each crop occupied 10 acres versus 100 acres or more. In addition, pest relationships can be expected to change with crop sequence and field size in adjacent farming units. The introduction of rotations does not alter the fact that most individual rotation crops are grown singularly, except for forage mixtures and for cover crops seeded in species mixtures. However, the practice of crop rotations on an individual farm basis would materially decrease monoculture and increase spatial heterogeneity.

(2) Adoption of a given rotation designed to reduce the incidence of a specific pest can provide a suitable environment or alternation of environments for new weeds, diseases, and insects.

(3) Crop rotation should be considered as an element of diversity distinct from diversity added through the use of trap crops and certain soil-conservation practices, such as grass waterways and windbreaks. Some practices recommended for soil conservation may not have any obvious relationship to pest management. Conversely, certain practices may affect the incidence of insects and diseases and subsequent crop damage. Strip farming may increase the severity of grasshopper attacks, damage from wheat sawfly, damage from chinch bugs on small grains, corn, and sorghum, and damage caused by various species of cutworms on legumes, small grains, corn, and other row crops. Similarly, favorable insect environments can be created by the need to provide adequate soil cover and by planting trees and shrubs for controlling soil erosion.

(4) The sequence of crops in rotation can be effective in reducing damage from certain root-rot diseases, cutworms, and other soil-inhabiting insects, and nematodes. The beneficial effects of a given rotation in pest management, however, may be restricted to a relatively narrow soil-climate zone. Thus, rotations that are effective in south Georgia in controlling root-knot nematodes in tobacco are ineffective in other tobacco-growing areas (Gaines, 1968).

In the absence of field experimentation, rotations may fall into disrepute as an important ingredient in pest-management systems. This is especially so when pest resistant varieties and other pest control practices reduce the need to introduce less profitable crops into crop rotation schemes.

Before the development of herbicides, crop rotation was a major element in weed-control programs. The effectiveness of these rotations depended on current understanding of the ecology and life history of a weed species and on information on conditions that favored its spread. Rotations and cultural practices helped in controlling such troublesome weeds as bindweed, hoary cress, and mustard.

A thorough knowledge of life histories and host plants of the many fungus diseases, insects, nematodes, and other organisms that attack crops is also essential before a given rotation can be stated as able to control a pest that is a characteristic feature of a monoculture or haphazard rotation. Take-all of wheat *(Ophiobolus graminis)* was particularly serious in the newer cereal-growing areas of Canada, Australia, and South Africa. It could be controlled through the use of comparatively short rotations (Garrett, 1942). In a similar vein, one can cite many examples in which rotations have been relied on to reduce nematode damage in a variety of crops. An example is the use of alfalfa in rotation to reduce nematode damage to sugarbeets and cotton.

A change in cropping practice can lead to a reduction in certain pests and to increases in others. Greater diversification in the crops grown in Arkansas apparently improved the food supply and the environment for certain pests including grasshoppers, blister beetles, chinch bugs, corn rootworm, bean leaf beetle, pea aphid, and bollworm (Isely, 1942).

A principal reason for the demise of crop rotations in many areas is that monoculture, plus associated technology (pesticides, heavier fertilizer inputs, tillage practices, and residue management) is more profitable to the farm enterprise. Rotations could return on a large scale if (1) alternate crops in the rotation were as profitable as the monocultural crop, (2) the associated practices did not continue to provide the benefits of rotation in such things as pest management and erosion control, or (3) if subsidies to achieve societal goals or penalties for contributing to environmental degradation were to offset the decreased economic return resulting from changing from a monocultural to a rotational system.

Crop rotations introduce diversity into agricultural ecosystems. It is dangerous, however, to regard rotations as a cure-all for lack of diversity. In reality, the most complex rotation represents a very simplified system in comparison with natural ecosystems.

Much of the early rotation research was conducted with susceptible crop varieties and there is little information on the contribution that crop rotation could make to well-designed pest management systems. These systems should include not only various crop rotations but also pest-resistant varieties, reduced pesticide inputs, improved soil fertility programs, and new soil and crop management practices. In brief, crop rotations can serve as a valuable tool in managing soil and water resources and in reducing pest damage. However, the rotation of crops cannot be evaluated thoroughly without reference to all aspects of the agricultural ecosystem, including both economic advantages and disadvantages to the producer and to society.

Conversion to Nonagricultural Use

The entire subject of diversion of current cropland to nonagricultural use should be viewed cautiously. Before the end of this century, population growth in the United States may make mandatory the use of additional acreages of land for crop production. When, or perhaps if, that time occurs, we will doubtless regret the folly that allows some of our best agricultural land to be lost to factories, residential development, and parking lots as a matter of current short-term economy and convenience. Instead, the best agricultural land should be diverted into uses from which it can readily be reclaimed for agricultural use if needed. A strong program of land-use zoning would facilitate this. Responsible agencies now have neither the political strength nor the factual information to make such decisions credible to their constituencies.

Nonagricultural uses of land that come readily to mind are residential, industrial, commercial, transportation, recreational, and wildlife. Residential, industrial, and commercial can be considered together as urban uses and demand for land for these purposes has been steady. Land has been taken for urban uses almost as a direct function of population increases—something in the range of one-fourth to one-third acre per person. Thus, with an estimated increase of 80 million people in the next 30 years, some 20 to 25 million acres of now rural land will be converted to urban uses.

The geographic distribution of these new urban land uses can be, to some degree, influenced by State and Federal action. We have had considerable concern over excess concentration of population and discussion of improved population balance, creation of new towns, and so forth. The possibilities for effecting a more even distribution of population and economic activity throughout the nation seem considerable. The concern about population concentration has some similarity to the concern over monoculture.

Interspersion of urban areas and agricultural land merits further study and experimentation along the lines proposed by Ebenezer Howard and others (Wunderlich and Anderson, 1971) (fig. 7). Farsighted strategies for power-plant siting, population redistribution, rural development, water supply, sewage disposal, city planning, and providing adequate health, education, and recreation facilities might all be combined with innovative land use planning so as to make progress in solving all these problems in concert. Such strategies could, but not necessarily would, have an impact on spatial heterogeneity in agricultural landscapes.

In most agricultural areas, the conversion to nonagricultural use is not likely to occur rapidly or widely. This is especially true of areas that now are extremely monocultural. These areas today are not densely populated, so they do not have any large unfulfilled need for nonagricultural uses. Further, the extremely monocultural areas are not particularly valuable for recreational uses. Under these conditions, there is little pressure or incentive for change.

Inducements could be offered that would have a tendency to break up the areas now devoted to extreme monoculture. Many municipalities throughout the United States offer substantial inducements to business firms to locate manufacturing plants in their localities. Some of these are highly desirable and add greatly to the stability and opportunities for the local population. However, there is a risk that municipalities may offer too much in the way of tax concessions or other subsidies when compared to the long-range value of the plant to the community.

Government regulations could also be modified to encourage dispersion of manufacturing and other types of business to small cities in monocultural areas rather

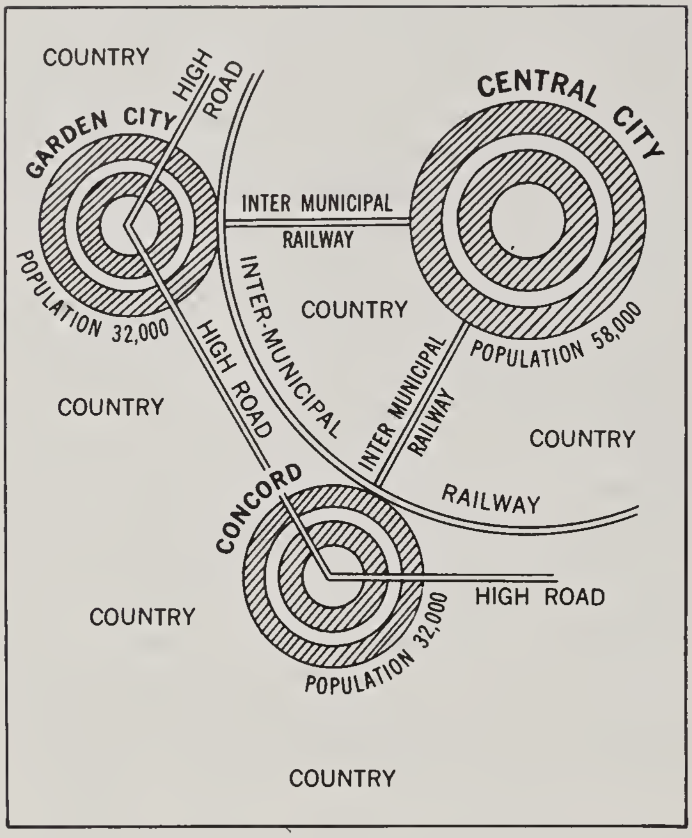

FIGURE 7–Ebenezer Howard's ideal concentric city (1898) had a glass-covered Crystal Palace in the form of a circular shopping street and a hierarchical care of culture and good government. The inviolate greenbelt separating it from its smaller duplicates was to be filled with sheep, grain, and orchards, instead of factories and cluster housing (Wonderlich and Anderson, 1971).

than their continued concentration in less numerous large population centers. Regardless of the route followed, dispersion of manufacturing plants would likely lead to a greater immediate cost of operation. At what point such a dispersal policy would begin to pay dividends in either economic or social terms is unclear.

Finally, if nonagricultural use of land is used to break up monocultural activities that now exist, an additional cost in efficiency will be assessed against the agricultural operation. Monocultures presumably now exist in given locations because those locations are most suitable for the production of that crop or small group of crops. If part of this most favorable area is devoted to nonagricultural use, larger areas of other land will have to be placed in agricultural production. The increase must come from lands less suited to the production of these crops than those currently devoted to such production. Again, assessing the time course or the total cost is difficult, particularly when those crops currently produced in conspicuous monoculture are in abundant to surplus supply.

Transportation routes already tend to break up the countryside. The new interstate highway system has rights-of-way averaging about 350 feet in width. In some stretches they are several times that width. Highway and railroad rights-of-way probably create barriers to the movement of some kinds of plant pests and diseases. They may also harbor plant and animal populations that lend diversity to the areas through which they pass.

As consumption of electrical energy increases and more generation facilities are located away from population centers, more transmission lines will be crossing rural areas. Currently, we have over 300,000 miles of overhead transmission lines preempting almost 4 million acres of land for rights-of-way. About 100,000 miles of new lines on 1.5 million acres of right-of-way are projected for construction each decade for the balance of this century. The usual practice in rural areas is for utility companies to purchase easements. Rights-of-way are kept cleared in forested areas but in agricultural areas regular farming operations usually continue under power lines except around the towers. These rights-of-way might provide opportunity to develop buffer strips of diverse plant species. Similarly, pipeline routes offer like opportunities.

Recreational uses—such as parks, hiking paths, and golf courses—can provide heterogeneity in land use and plant species in rural areas. The greatest need for such areas is near population centers with correspondingly less need in more isolated rural areas. Recreational uses often prefer rough and wooded land. Most areas of monoculture are characterized by even terrain and little rough land or wasteland. The need to introduce diversity is less in areas that have scattered areas of rough, uncultivated land, which is often left to go to climax vegetative cover. Hiking and biking paths are possibilities for breaking up large expanses devoted to similar crops, particularly if they are bordered by trees, shrubs, and grass.

Wildlife areas appear to have some definite advantages in providing more heterogeneity. The need is not related to proximity to human population centers and hence distribution has more geographic flexibility. Size, distribution, and type of terrain can be varied for different objectives in wildlife management and for increased heterogeneity in plant species. USDA supply management and resource conservation programs already provide incentives for taking tracts of land out of tillage, establishing permanent cover, and managing for wildlife conservation.

Partial Return to Native Habitat

Most biological disadvantages of monoculture stem from the lack of biological diversity in the landscape when large continuous areas are devoted to a single very limited plant community. This problem can be alleviated best, perhaps, by interspersing native vegetation (with its much greater internal diversity) rather than by interspersing other crops. The native vegetation will admittedly yield little or no monetary return, but some indirect effects may be worth more.

If one is considering the re-establishment of some native (or, better, spontaneous) vegetation in an area largely devoted to a single crop, one should aim at establishing as long a boundary between cropland and other vegetation as is consistent with the requirements of agronomic practices, and with maximizing the yield of the remaining crop area. Optimally, this implies long strips of cropland, wide enough for the effective use of modern equipment but not much wider, along the contours where topography is not level, and separated by narrower strips of spontaneous vegetation.

Other things being equal, areas of lowest potential for cropping would be left for spontaneous vegetation. Low-lying areas often would be good candidates to remove from cropping, and it might even be worth trying to establish ponds in hollows—even if this involves sealing a too-pervious substrate. Ponds with their associated riparian vegetation provide an area of outstanding local diversity, which can serve as a refuge for valuable species of insects and wildlife. If stocked with fish, these ponds can form a direct addition to recreational facilities and even to income. Similarly, the establishment or re-establishment of watercourses wherever the topography permits would be wise. The value of these watercourses would be negated if they were canalized so as to drain the surrounding land and allow water to run off quickly. Instead, a strip of land with the associated riparian vegetation could be allotted broad enough to permit the watercourse gradually to develop riffles, pools, meanders, and all the other features of natural creeks.

To speed up the benefits derived from this type of diversification, we suggest that the spontaneous development of vegetation in the areas released from cropping should be encouraged by a judicious planting program. Species for planting should be selected carefully. In general, species known to succeed, not only in the region, but in that particular ecological situation, should be chosen. A good mixture of species of different life forms—trees, shrubs, and perennial grasses and forbs—should be used so as to establish as early as possible a habitat of maximum structural diversity.

This suggestion amounts to a plea for landscape management inspired simultaneously by ecological considerations and by the need to optimize the farmer's economic position. Since the farmer would not be the only one to benefit from these changes, some measure of subsidization might be appropriate. Such a subsidization would, indeed, facilitate planning control.

Other Systems of Agriculture

One principal method by which environmental contaminants exit from agricultural systems, monocultural or otherwise, is surface runoff. Water carries sediment, nutrients, pesticides, and animal wastes away from agricultural lands. The predisposition of these potential pollutants to such transport is associated to a considerable degree with monoculture and intensive agriculture. Curtailment, or significant reduction, in losses of these materials from agricultural systems would partly counter some of the principal disadvantages of monocultural and other intensive agriculture.

Semiclosed systems.—One approach to accomplishing this loss could involve semiclosed systems in which potential contaminants are prevented from leaving. Such systems would involve terraces, catch basins, and impoundments to intercept the contaminants. To be effective such systems would require provisions for returning the contaminants to agricultural lands by various means. Sediment, water, and nutrients, all could be recycled, to a considerable degree, with potential beneficial effects on crop production. Probably such systems would not be completely effective or usable in all situations. They could range in size to accommodate single farms or groups of farms.

Coupled with cultural practices that minimize loss of these contaminants from land, semiclosed systems might offer considerable potential for greatly ameliorating environmental degradation from agriculture. They would have little effect on leaching of nitrates to ground water. However, such losses are not believed very great (Nelson, 1972) except in certain situations, which could be corrected through improved agricultural practices. Tiling could intercept leached nitrates for recycling.

Semiclosed systems would offer a potential for intensifying agricultural production. Higher production inputs might be possible in many situations if water availability were increased through recycling of runoff. Total production might be materially increased in the best agricultural land and the need decreased for use of lands most susceptible to mismanagement or most likely to contribute to environmental degradation. This, in effect, would continue the trend in the direction established by monoculture, large scale farming, and mechanization.

Closed systems.—This concept could be carried still further to essentially closed systems for the production of high-value crops. These systems probably would involve environmentally controlled enclosures, such as greenhouses and very large plastic bubbles, in which important environmental parameters are controlled at optimum or near optimum levels for the crops grown. Essentially everything not sold would be recycled. The need for weed, insect, disease, and nematode control would be minimized. At least, release of pesticides to the environment could be prevented. Energy requirements associated with electrical power for environmental control and other uses, possible mechanization, fertilizer, and other inputs probably would be high. But high levels of production should be possible with extremely minimal loss of environmental contaminants. Such production probably would be highly monocultural.

The economic potentials of closed and semiclosed systems in large-scale production do not seem great under present circumstances. We are not assessing these potentials. However, a technological breakthrough such as successful, safe, nuclear fusion might provide almost unlimited energy at very low cost. Many things, then, now prohibitive in cost would become economically possible. For example, land-forming on an extensive scale could facilitate semiclosed systems. Pumping of runoff back through the system would be more feasible. Furthermore, cheap power would greatly facilitate the transport of animal and human wastes over considerable distances and recycling through agricultural production systems, thus returning nutrients and organic matter to the proper sinks. Recycling of these materials through conventional agricultural production systems has received increased attention during the past several years with notable success (Gray, 1968; Swanson and Seitz, 1971, and others). Cost factors remain high, however, and pose limitations, but much more can be accomplished in recycling of wastes through conventional agricultural production systems.

Extensive use of closed or semiclosed systems as a possible modification of monocultures probably must await incentives such as substantial changes in the cost of energy, or subsidies for construction of such systems. They might also become necessary to some degree as a result of legislation.

High-labor systems.—The return of agriculture to a system of smaller farms using less machinery and more human labor has been suggested. This probably would result in increased diversity in agricultural landscapes and enterprises.

Most of the Task Force agree that a large-scale return to this type of agricultural system presents too many obstacles. The physical operations of farming would be more costly per unit of production. Total production probably would be decreased with consequential increases in food costs to society. Labor probably would not be attracted to such work unless wages for farm labor were materially increased and, if this occurred, food costs from such production would be higher still. Marketing costs for this type of operation would be materially increased. In a free enterprise system, such enterprises would be at a decided competitive disadvantage. Indeed, this is why the old system gave way to present styles of agricultural production. The small enterprise having a high labor input marked an evolutionary stage in American agriculture that could not remain viable in our changing economic system. Drastic changes in the economic and political system would be necessary to make it viable in the future. Or, some emergency event such as an extreme shortage of energy might force the issue.

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6. RESEARCH RECOMMENDATIONS

Monocultures developed in American agriculture for many reasons. Probably the most important one is the maximization of income through a combination of efficient, mechanized cultural practices and crop species that are biologically highly efficient or have high market value. Other factors also were important. Whatever the causes, the net result is a very productive agricultural system in terms of quantity and cost of production. American farmers will probably not abandon monocultural cropping without an equally or more profitable alternative.

But modern agriculture is not without its shortcomings. These relate mostly, but not entirely, to deleterious effects on environmental quality. During the past few years agriculture has been severely criticized in that regard. Regarding some criticisms, however, neither agriculturists nor environmentalists have appropriate information. In some others, agriculture seems clearly at fault.

The following recommendations for research activity are based on::

(1) Identification of research areas in which additional information is required to correctly assess the extent, if any, of monoculture's role in environmental degradation.

(2) Provision of an information base for correction of problems in acknowledged problem areas.

(3) Definition of areas that have some potential for reversing the trend to monoculture.

(4) Research in a few areas somewhat peripheral to the central theme.

Inventory of Landscape Diversity and Trends

The Task Force recommends that efforts be directed toward an inventory of landscape diversity and monitoring trends in diversity. This research should:

(1) Provide a definition of landscape diversity applicable to spatial scales and develop efficient means for measuring various aspects of landscape diversity;

(2) Describe the extent of landscape diversity (spatial heterogeneity) in the United States;

(3) Examine historical trends in landscape diversity in the United States and project possible future trends;

(4) Catalog the status of factors associated with landscape diversity in various areas.

Application of available theoretical constructs to develop a measure or measures of spatial heterogeneity or temporal heterogeneity in agricultural landscapes is difficult. Further, available data probably will limit measurement in the desired number of aspects.

Basic to further consideration of the implications of monoculture (lack of spatial heterogeneity) is a suitable methodology for defining the status of landscape diversity and describing the extent of monoculture. This will involve the use of existing data, the accumulation of necessary new data, and the development of models, suitable formulae, and so forth for calculating diversity indices. Initial exploratory efforts probably should be directed toward developing techniques that could be used nationwide.

A possible approach might employ data accumulated by the Corn Blight Watch Experiment in 1971. This experiment provided a catalog of agricultural characteristics of a seven-State area in the Midwest, an area of extensive monoculture. Available data on crop acreage, field size, and other parameters would provide a quantitative measure of diversity and a base for testing the effectiveness of various indices of diversity.

Diversity indices will aid in delineating areas representative of parts of the continuum from a heterogeneous to a homogeneous pattern of diversity. By selecting geographic areas with different diversity indices, various statistical approaches could be employed to study associations between degree of diversity and other parameters such as size of field, size of farm, and disease incidence.

Exploratory research should provide an adequate model that could be extended to the measurement of diversity by region or for the Nation as a whole. These studies could involve the use of powerful remote sensing techniques and should suggest additional meritorious research.

Systems Analysis

The Task Force recommends a systems analysis approach to a study of spatial and temporal patterns in agricultural landscapes and enterprises to be used as a basis for:

(1) Projecting biological, economic, and social consequences of possible future changes in cropping patterns;

(2) Organizing available data to identify knowledge gaps and provide guidance for establishing research priorities;

(3) Understanding the interactions that occur with different spatial and temporal patterns and scales in agricultural landscapes, using perspectives of various disciplines;

(4) Developing models for more rational private and public decision making.

Systems analysis of pattern effects might take place at three scales: (1) the individual field, (2) the farm enterprise as a unit, and (3) the local region or community. Different considerations and types of Interaction apply at these different scales. At each scale, one might choose to concentrate on particular alternatives for the structure and operation of agricultural enterprises, and particular measures of the resulting effects.

The first attempt at systems analysis could be related to the function of pest management, a highly important topic at this time, and the systems analysis could provide a valuable input to this area. Studies now in progress under the auspices of the International Biological Program (IBP) relate to this topic, and it is envisaged that the study proposed here would relate to some of the IBP research, although it would largely develop independently.

A systems analysis along the lines proposed would be best organized by combining a small continuing full-time group with a larger workshop group that would meet periodically over a span of time. This larger group would provide the necessary detailed biological and economic expertise that could not be expected within the systems-analysis group proper. It is highly important that the membership in the Workshop group represent outstanding interdisciplinary capability in relation to the pest complex. The leader of the systems-analysis group should be a capable biologist with additional capability in systems analysis rather than a systems analyst with no biological background.

Relationships Among Scale, Technology and Monoculture

We recommend that the relationships among scale of farming, levels of technology employed, and monoculture be established to:

(1) Clarify the alleged effects on environmental quality resulting from increased monoculture, fertilizer use, pesticide use, erosion, energy consumption, and other significant variables;

(2) Provide needed relevant information for future agricultural policy formulation.

Often the increasing trend to monocultural agriculture is assumed to result from larger scale of farming and increased use of technology. Frequently monoculture and technology are alleged to result in increased environmental degradation as a consequence of larger inputs of fertilizer, pesticides, and energy. However, we do not know whether (1) farmers who are less diversified use more fertilizer, energy, and pesticides per acre than those who are more diversified; (2) areas of less diversification have a higher incidence of crop pests than do more diversified areas; (3) large farms diversify more or less than small ones; (4) diversification of present monocultural areas would require larger technological inputs over still larger areas; and (5) diversification leads to more or less farm income.

In short, the relationship between diversity and factors that affect the environment and the socioeconomic structure are not known or, at least, are poorly understood. These relationships require definition before the impact of monoculture on the environment or socioeconomic structure can be accurately assessed. Furthermore, if environmental insult from monoculture is indicated, we need to know the extent and severity of that insult and determine effective measures for its elimination.

The development of monoculture has by no means only negative results. There are advantages to the entrepreneur and to society that may offset the drawbacks to which attention has been directed. We should at least consider correcting the shortcomings of monoculture and not necessarily assume that we must abandon it. Monoculture must not be equated *a priori* with scale or intensity, or both, of agriculture in the process of clarifying these relationships. They may often be associated, but they need not be.

One aspect of scale that might well receive attention is that of the part-time farmer. Usually, these farmers operate smaller units. Information is not available concerning the cropping patterns of these part-time farmers in relationship to neighboring full-time farmers. In some areas where monocultures exist, part-time farmers could contribute to a more desirable level of diversity, while in other situations the reverse might be true.

The role of these farmers in spatial heterogeneity and the potential for increasing these contributions to diversity should be determined. In addition, any unique problems that might arise, whose solution would contribute to maintaining or increasing contributions to greater spatial heterogeneity should be determined.

Research Effects and Monoculture

We recommend that added research emphasis be placed on crops and on technologies that have economic potential for increasing diversity in cropping patterns and enterprises. We also recommend an analysis of the effects of past resource allocation on development of monocultural systems.

The relationship of research input to technology and to resulting cropping patterns was discussed in ch. 3. Heavy research inputs on a given commodity, continued over a period of time, will increase profit levels of that commodity and, consequently, the extent to which it is grown in monoculture. This relationship is not well appreciated, or, if it is, the long-term consequences are not. In some crops, such as wheat, the monoculture was probably inevitable because of climatic limitations that precluded significant competition from other crops. But in most monocultures technological advantage has been an important factor both in establishing and maintaining the monoculture.

The impact of research usually follows the research itself by some period of time. Furthermore, the consequences of research are not always readily predictable. Thus, it becomes important to find better methods for examining the probable research impact, from a broad societal viewpoint, to develop research programs that are in the best interests of society.

If increased crop diversity is determined to be a worthwhile goal, then changes in future resource allocation will be essential.

In our agricultural system, composed largely of individual entrepreneurs, farmers decide on choice of crop, largely on the basis of economic return to the enterprise. Operating within such a system, it follows that the principal way that present monocultural cropping patterns could be modified would be development through research of technology that would make alternative crops or farming systems more competitive choices for investment capital. Conceivably, such measures as Government price support programs or conservation programs could be modified to provide additional incentive, but discussion of these possibilities is beyond the scope of this Task Force.

Studies should be undertaken by highly knowledgeable interdisciplinary groups to identify research of high impact potential. Two examples are as follows:

- Research on induced twinning and associated technology in beef cattle. Twinning capability would have tremendous impact on livestock management systems and consequently on the demand for various kinds of livestock feeds (Hodgson and Hodgson, 1970). Such technology appears to have high potential for diversifying cropping patterns and farming systems.
- New methods for harvesting and storing alfalfa and other forages that would minimize dry matter losses, minimize time and labor inputs, and reduce the risk of investment loss. No significant advances on such technology have occurred for forages in the last 10 to 15 years, while many advances have been made in handling the corn crop. Yet, this lack of modern methods is probably the most important factor in limiting the choice of alfalfa and other forages as desirable crops for investment capital. If adequate improvement of forages as a choice for investment capital is attained, forages would be grown on greater acreages and contribute to increasing crop diversity.

Genetic Diversity

The Task Force urges immediate increased research effort to halt genetic resource depletion in major crops and cropping systems. Such research should lead to:

(1) Use of genetic diversity to reduce vulnerability to hazards within established crop species;

(2) Maintenance of genetic diversity in possible agents of biological control.

The world population is dependent on a relatively few plant species for its food supply. Plant breeders have been remarkably successful in developing high yielding new varieties of these species through selection and the production of hybrids. Several important food crop species are self-pollinated with a continuing built-in thrust to homozygosity and, in man's hands, a narrower gene base. Many important crop varieties and hybrids now have rather narrow gene bases. Furthermore, corn breeders incorporated the same cytoplasm into most hybrids of corn. This situation is now largely corrected, but the tendency toward use of cytoplasmic male sterility in producing hybrids in other species continues the trend toward uniformity and increased vulnerability.

There is little doubt that our important crop varieties and hybrids are based on rather narrow genetic resources (ch. 4). Many hybrids and varieties in some species are closely related. In the process of developing improved varieties, we have discarded many genes and genetic combinations that were not immediately useful.

The trend to monoculture with important crops tends to concentrate a single variety with a narrow genetic base over large, contiguous areas. To protect such varieties from pests to which they have no genetic resistance or limited resistance, pesticides are used, often in large quantities. Furthermore, large acreages of varieties with a narrow genetic base provide an ideal situation for the explosive buildup of new pests or new mutant races of existing pests.

The Task Force views this situation as an extremely important problem and recommends that, with minimal delay, increased public research efforts be directed to devising breeding methods and developing germplasm with broad genetic diversity. A plausible approach to initiate this action might be to organize workshops for important crop species to develop strategies for increasing genetic diversity.

We realize that uniformity is a highly desirable trait for many crops that are mechanically harvested, but great care is needed to maintain broad genetic diversity for other traits. The matter of collecting and retaining germplasm from wild germplasm pools now being rapidly decimated also requires attention. The safeguarding of our important crops from genetic vulnerability may well be a most important current and future responsibility of public plant breeding research. The entrance of the private sector into breeding many of our crop species should permit public agencies to reallocate some resources toward this important responsibility.

The considerable stability inherent in natural ecosystems is not based on species diversity alone but to a considerable degree is due to genetic diversity within species. The elaborate mechanisms that have evolved in plant species in natural ecosystems to insure cross-pollination and heterozygosity in the population attests to the relationship of genetic diversity and stability. Therefore, greater genetic diversity in crop cultivars would probably reduce susceptibility to disaster by pests.

The trend to monoculture with larger fields and greater contiguous areas of a crop has reduced crop diversity and eliminated fence rows and similar areas where more or less wild plant populations grew. This trend has destroyed breeding places for important plant pests and alternate hosts of others. Conversely, it has contributed to the destruction of habitats for the agents of biological control of many pests and cumulatively resulted in decimation of the pool of genetic resources of these agents.

The Task Force recommends that more research be directed to determine the effect on pest populations of decreasing crop diversity with the resulting elimination of natural habitats for agents of biological control, and to determine if increases in diversity and re-establishment of breeding grounds would improve pest management systems. The size, frequency distribution, and botanical composition of such areas should be studied, together with the population trends of potential parasites and predators.

Pest Management

The Task Force believes that some aspects of the broad area of pest management require additional research inputs to:

(1) Establish ecologically sound principles and economically feasible practices that promote a more rational use of pesticides;

(2) Review quality standards for agricultural products with reference to possible environmental effects of the pesticide levels required to achieve those standards;

(3) Examine tradeoffs among alternative management strategies such as crop rotation, spatial pattern, pesticides, pest resistance, and life cycle interference;

(4) Evaluate and specifically classify all important host-pest situations on the basis of their economic severity in relation to intensity of monoculture.

Although these recommendations are not necessarily peculiar to monocultures, situations discussed here often occur in monocultures and increased crop diversity is a component of some pest-control strategies. We believe that successful achievement of these research goals will require interdisciplinary research and coordination.

Pesticides often are used when they are not needed or used at higher rates per year than necessary. Such a situation may arise because of inadequate information concerning pest populations that can be tolerated in a crop before chemical control is needed. Furthermore, interactions among environment, pest population, and the economic need for control are not well understood. Development of a more rational model for decision making in pesticide use will benefit all intensive agricultural systems including those developed to intensive monoculture.

Quality standards for many agricultural products demand a product that is almost perfect in appearance. Often these standards have little or no relationship to the commodity's value to the consumer. To meet these market standards, producers often must use high levels of pesticides, contributing to excessive pesticide use. Research on the relationship between pesticide usage and product-quality standards and between quality standards and utility to consumer seems appropriate. Such information would provide a base for educational programs pointed toward eliminating excessive pesticide usage to produce excessive appearance quality.

Several management strategies exist for controlling pests in any crop-environment situation. Among these are pesticides, spatial pattern, crop rotation, pest resistance, and various biological-control measures. The proper combination of these strategies is required to optimize pest management in specific environments. The systems analysis approach could make significant contributions in this regard. We do not have the necessary information on tradeoff values for various strategies. Research to acquire these values should have high priority.

The Task Force had no difficulty in identifying specific pests whose control becomes more troublesome with increased monocultural practice, others that were less troublesome, and some that were unaffected. The assumption that monoculture automatically intensifies all pest problems is not valid, but the situation needs to be documented. Individual cases, not generalized assumptions, must be considered in pest-management strategies.

The Task Force is aware of accelerated research inputs in pest management. These suggestions underscore the need for expanded research activity in this problem area.

Energy Dependency

The Task Force recommends an increased awareness of the vulnerability of modern agriculture to energy supply.

Agriculture is very energy-dependent (ch. 4). Much of the energy source consists of fossil fuels. Energy dependency is closely related to the degree of mechanization. If recent mechanization trends continue, this dependency on fossil fuel energy will become even greater.

Frequent reports have appeared in the press during recent years regarding exhaustion of fossil fuel supplies. Such reports imply shortages of certain types of fossil fuels before the end of this century. Recent reports indicate that an energy crisis might occur much sooner. World situations that would effectively reduce fossil fuel imports would cause serious energy shortages.

Serious national energy shortages undoubtedly would result in the establishment of national policies on energy use. Food production would seem to be an activity of high priority but, even so, restrictions on energy use and increased costs could be anticipated.

Therefore, the Task Force believes that an increased awareness of potential energy shortages with resulting increases in energy costs to agriculture is warranted. Research agencies should consider ways in which agriculture could cope with such a situation. A return to human or animal energy as a substitute would be an acceptable alternative but is improbable. Therefore, other alternatives that permit sustained production with reduced energy supplies or higher energy costs should be studied.

Alternative sources of energy such as nuclear energy, solar energy, and hydrogen have been advanced as substitutes for fossil fuel. That they will be needed in the near future seems certain. Therefore, in view of agriculture's energy dependent status, agricultural administrators could emphasize agriculture's future energy needs to agencies with responsibilities for energy development research. Furthermore, support for increasing research on new energy sources should be encouraged by all segments of agriculture.

Monoculture and Economic Vulnerability

We recommend research appraising the regional and national economic impact of varying degrees of failure of important crops, and relating the potential of degrees of crop failure to the risks of monoculture.

Agriculture is not an island unto itself. It is inextricably interwoven into the total fabric of the Nation's economy and that economy's nourishment. Sharp changes in the economic status of agriculture are quickly felt throughout the total national economy. Shortages in supply of important commodities will affect labor and management in the processing, transportation, and marketing industries, and have sharp repercussions on the prices of these commodities to the consumer. Similarly, the effects will be felt by those industries that contribute major inputs to the production of these commodities.

In short, the vulnerability of essential crops would have important national and regional consequences. The relationship of monoculture to the threat of crop failure and economic disaster should be studied and documented. If significant, ways to ameliorate the effects of extensive monocultures should be researched to find methods reverse the trend toward monoculture in crop production.

Agricultural Practices and Environmental Quality

The Task Force believes that in the future society will require increased capability to predict runoff contamination in different management systems. The relationships between agricultural practices and environmental quality should be clearly established, and methods should be developed for assessing damage levels resulting from alternative land management systems.

Land use and management are of increasing importance because of the growing public awareness of environmental problems and the realization that the effects of land management extend beyond the boundary of the land parcel itself. In a sense, sound use and management of land consist of reconciling the highest value land use for the owner with the best interests of society.

In agriculture certain monocultural systems, because they involve large land areas in common husbandry practices, may contribute to increased runoff and, potentially, to high contamination of runoff with such matter as sediment, pesticides, and nutrients. This problem, however, is not peculiar to monocultures.

The prospect of legislation or regulation at national, State or community levels, the development of wise land use and management practices, and the establishment of the value of damages when legislation or regulatory codes are violated require a much higher capability to predict runoff levels and runoff contamination in different environments under various management systems. Such capability would be especially useful in developing rational legislation and in guiding the land owner or user toward satisfactory use and management.

Land Tenure and Spatial Heterogeneity

We recommend that research on the interrelationships of land tenure and spatial heterogeneity be initiated. If the research indicates that certain forms of land tenure appear to impede the achievement of desired levels of spatial heterogeneity, modifications of these forms of tenure should be developed.

Land-tenure arrangements include a wide variety of means by which a farm operator gains and maintains control over the land resource. Ownership may take the form of a single proprietorship, a partnership, a family corporation, or other corporate forms involving vertical integration. Further, the financing source used to gain control through ownership has a potential for affecting the land-use patterns. Renting arrangements include cash, crop-share, and livestock-share leases with many variations in the specific provisions of each.

If a differential impact of tenure arrangement on spatial heterogeneity is evidenced, the mechanism by which the impact occurs needs to be described. Provided that public policy requires an increased level of spatial heterogeneity, implementation of such a policy might include programs stimulating shifts to those tenure forms, if any, which favor increased spatial heterogeneity.

Spatial Heterogeneity and Part-Time Farming

The Task Force recommends investigation of the potential effect of part-time farming on spatial heterogeneity.

Many farmers now earn a substantial part of their incomes from off-farm work. Usually, these farmers operate smaller units. Information is not available concerning the cropping patterns of these part-time farmers in relation to neighboring full-time farmers. In some areas where monocultures exist, part-time farmers could contribute to diversity, while in other situations the reverse might be true. Most part-time farmers probably are concentrated around population centers where off-farm work opportunities are greatest.

The role of these farmers in spatial heterogeneity and the potential that they have for increasing the diversity of agricultural landscapes should be determined. In addition, any unique researchable problems connected with part-time farming whose solution might increase the contribution of this type of farming to improved spatial heterogeneity should be determined.

Spatial Heterogeneity and Recycling of Organic Residues

The Task Force suggests research concerning (1) the potential of organic farming, (2) recycling of wastes via agriculture, and (3) fuller use of agricultural residues in increasing landscape and enterprise heterogeneity.

Recently, organic farming has received substantial interest. The reasons underlying such interest contain considerable fiction as well as fact. Paralleling that interest, although not necessarily associated with it, is the increasing desire on the part of many urban people to own a small tract of land in the country where they can farm on a small scale, more or less as a hobby, and where their families can experience the learning that comes from first-hand experience with nature.

Public agricultural research agencies in general have been critical of organic farming, or at least they have had that reputation. Perhaps this is related to that part of the arguments advanced for organic farming that most agriculturists consider to be unacceptable. Yet, an opportunity to identify research needs that would help organic farmers improve their practices seems worthwhile. Exploring these research opportunities with leading advocates of organic farming seems desirable.

Organic farmers and hobby farmers usually operate on a small scale. Yet, wherever such operations are strategically intermingled in monocultures, they might furnish unique islands of unusual crop and wild plant diversity that could be important in pest management systems.

The recycling of both agricultural and nonagricultural wastes through agricultural systems–including effluents from urban sewage treatment plants–might be a vehicle that could contribute to increasing spatial heterogeneity, especially if disposal systems involve a variety of crop species.

Millions of gallons of "relatively pure" water are discharged from sewage treatment plants in the United States every day. Most of this water, carrying a large amount of plant nutrients, finds its way into streams and lakes, causing serious pollution problems. This effluent should be regarded as a valuable resource for crop production. Sewage effluent is used for irrigation in a few places in the West but information as to its safety, nutrient qualities, economic values, and effect on the soil is very scant. This area of study would respond quickly to research on a team-effort basis.

Even in areas where irrigation is not a common practice, application of sewage effluent to the land offers the possibility of an effective solution to pollution problems. The absorptive and regenerative qualities of the soil have not been exploited as they should have been. Indeed, here is another area where agricultural scientists have the key to the solution of a serious national problem.

Spatial Heterogeneity and Aesthetics

The Task Force recommends that research be directed to:

(1) Evaluation of the magnitude and seriousness of aesthetic deprivation of persons more or less constantly exposed to monocultural agricultural systems and the potentials for introducing types of diversity that do not interfere with agricultural efficiency;

(2) Evaluation of the role of agriculture in maintaining landscape aesthetics for urban and suburban populations.

Aesthetic monotony, apparently, is not a substantial problem to persons living in areas of monocultural agriculture (ch. 4). These areas represent a small part of our population that have a financial interest in that type of agriculture. Their daily activities expose them to levels and types of diversity not noticeable to the casual tourist. Yet, opportunities may exist for introducing types of landscape diversity that would add aesthetic value for both indigenous and tourist populations without interfering with agricultural efficiency. These possibilities should be evaluated and exploited. Perhaps potentials exist for combining such new diversity with attempts at ameliorating other problems of monoculture.

The most important thrust for agriculture in landscape aesthetics would be associated with maintaining aesthetic values in the landscapes of developing urban and suburban areas. Particularly important is the opportunity associated with population redistribution activities and the development of new cities. Landscape aesthetics are closely associated with land-use planning, an activity that draws on expertise in USDA and Land Grant Universities. It seems highly appropriate for those agencies to expand their research activities related to maintaining aesthetic qualities in future land-use planning. Even more appropriate would be for these agencies to exercise initiative in becoming involved with other agencies also implicated with such activities as land-use planning and population redistribution.

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APPENDIX

A MINORITY REPORT ON THE ECONOMICS OF SPATIAL HETEROGENEITY IN AGRICULTURAL ENTERPRISES[3]

Introduction

American agriculture has always tended toward homogeneity. The reason farmers do not grow a more heterogeneous mix of crops is economic. The most common defense of current agricultural practices is economic. We, therefore, have an obligation to examine the reasons behind this lack of agricultural diversity.

We shall see in our discussion just what economic factors have led to the increasing homogeneity in U.S. agriculture:

(1) An abundance of cheap, fertile land facilitated the creation of new farms, thereby leading to intense competition in agriculture;

(2) The low returns to agriculture resulting from the intensity of competition required that a farmer employ more land to earn a living;

(3) The mechanization of agriculture that developed as a response to the increasing farm size created technical conditions that in time amplified the tendency toward larger farms;

(4) Low energy prices drastically cheapened the cost of mechanization;

(5) Tax laws and subsidies encouraged large corporations to enter into agriculture, doubly confounding the problem by further lowering the rate of profit in farming; and

(6) The desire for monopoly profits further encouraged large agribusiness corporations to vertically integrate their operations.

According to a USDA report in 1906, "The success and prosperity of the American farmer are due to the unbounded fertility of the soils, the cheapness of the farm lands, and the privilege of utilizing modern inventions in machinery rather than to systematic organization and efficient farm management" (Hays and Parker, 1906).

In a letter to Arthur Young, a careful observer of English agriculture, George Washington wrote, "The English farmer ought to have a horrid idea of the state of our agriculture . . . men are fonder of cultivating much than cultivating well" (Habbakuk, 1967). Actually, fondness was less important than sheer economic reality. A farmer could not make a living on a small plot of land. Economic necessity forced him to cultivate extensive tracts, and he had neither the time nor the resources to maintain the fertility of such wide stretches of land.

The same economic incentive for large-scale agriculture exists today. No farmer can support himself on what he can grow in a flower pot and, with farm prices low in relationship to other prices, a small farm is not much better than a flower pot. High profits in agriculture accrue to the farmer who has extensive acreage. In general, the larger the farm, the higher the sales. Table 5 shows the relationship between farm sales and realized net farm income per hour.

TABLE 5—Farm sales and realized net farm income, 1966

Farm sales	Operator and family labor	
	Labor per farm	Realized net farm income per hour
	Hours	*Dollars*
$20,000 & over	2,114	$8.30
$10,000 to $19,999 . . .	2,125	3.22
$5,000 to $9,999	1,978	2.00
Under $5,000	1,214	.88

Source: Fuller, Varden, and van Vuuren, Willem. Farm Labor and Labor Markets. In Size, Structure, and Future of Farms, A. Gorden Ball and Earl O. Heady, eds., Iowa State University Press, Ames, Iowa. 1972. pp. 144-170.

Now let us evaluate the way in which some other economic pressures have affected agriculture. As mounting farm surpluses held farm prices back, U.S. farmers adopted technology designed to cut labor costs. In fact, this technology, in general, tended to cut labor costs by

[3] This minority report was written by Dr. Michael Perelman, assistant professor, Chico State College, Chico, Calif.

substituting natural resources and equipment for manpower. This policy made sense; we had much land and little labor. Moreover, cheap land offered the wage earner an alternative means of livelihood when wages sunk too low. "Where land is in such plenty," wrote one observer in the 1760's,

> . . . men very soon become farmers, however low they set out in life. Where this is the case, it must at once be evident that the price of labour must be very dear; nothing but a high price will induce men to labour at all, and at the same time it puts a conclusion to it by enabling them to take a piece of waste land. By day-labourers, which are not common in the colonies, one shilling will do as much in England as half-a-crown in New England" (Habbakuk, 1967).

In effect, cheap land provided a floor below which wages could not fall, and relative to the wage rates in other nations, this floor was high. More important, wages were high relative to the cost of machines. This combination of high-wage rates and relatively cheap machinery gave farmers an economic incentive to buy labor-saving machinery. The economic motive for adopting labor-saving technology was reinforced by the farmer's attitude toward the working man. For instance, one State salesman for Cyrus McCormick's Reaper Company took it as the object of his work to "place the farmer beyond the power of a set of drinking harvest hands with which we had been greatly annoyed" (David, 1966).

The labor-saving inventions had two effects: (1) The workingman was more productive and this productivity made the Nation more prosperous, and (2) the worker was more expendable. The new technology also reduced labor's share of the new prosperity. In 1850, wage earners received 80 percent of the national income. By 1910 they earned only 74 percent, and by 1938 the percentage had fallen again to 66.5, approximately where it stands today (Habbakuk, 1967).

But while labor's share of the total national income stabilized, mechanization of agriculture depressed labor's share of agricultural income rapidly. In 1970, labor's share ranged from a high of 44 percent in the Lake States to a low of 21 percent in the Corn Belt. In almost every region, labor's share in agricultural income was about half as high as in 1950 (Lianos and Paris, 1970).

This decline is not too surprising. Farmworkers and small farmers have very little power in our economy—they do not have powerful unions to back up their demands. As a result, their incomes are small. However, if their earnings were comparable to those of industrial workers, their share of the total agricultural income would be much closer to the average share of labor in the national economy.

The real surprise in modern agriculture is the rise in productivity that took many economists by surprise. These economists believed that somehow the farm was not amenable to rapid progress. Their reasoning followed the central theme of Adam Smith's *An Inquiry Into the Nature and Causes of the Wealth of Nations*—that technical progress depends on the division of labor. The example cited in his book (Smith, 1937) showed a small pin factory greatly increasing the productivity of labor by reorganizing the production process.

Economists pointed to three reasons for this increased productivity: (1) Workers wasted less time shifting from job to job; (2) they could become more skilled in their individual specialty; and (3) equipment could be more continuously used (Georgescu-Roegen, 1971).

The economic advantages of reorganizing production were so great that within about 100 years of Smith's publication, industrial production was almost completely restructured along the lines he recommended. By that time capitalists had to buy bigger and better machinery to increase their workers' productivity. Economists reflected this change in viewing the workers' productivity as a product of the capital with which they were supplied. But farmers still grew their crops in much the same fashion as their forefathers. Some had reapers and threshers and could produce more than the earlier farmers, but the organization of farming was relatively unchanged.

Many of the great economists who lived before the start of agriculture's transformation thought that agriculture could never make the progress analogous to the conversion of the cabinetmaker's shop to the furniture factory. John Stuart Mill wrote:

> Agriculture . . . is not susceptible of so great a division of occupations as many branches of manufacturers, because its different operations cannot possibly be simultaneous. One man cannot always be ploughing, another sowing, and another reaping. A workman who only practiced one agricultural operation would lie idle eleven months of the year. The same person may perform them all in succession, and have, in most climates, a considerable amount of unoccupied time (Mill, 1909).

Alfred Marshall, the next great systematizer after Mill, also accepted the impossibility of the industrialization of agriculture (Marshall, 1936). He said that agriculture "cannot move fast in the direction of the methods of manufacturing." But about the time of Marshall's death, something started to happen. Until then, most of the increases in farm productivity could be explained by capital replacing labor. Suddenly with just a little extra investment, output jumped (Tweeten and Tyner, 1965).

The harnessing of fossil fuels was a major factor in this spurt of agricultural productivity. As late as 1920, more than 20 million horsepower was provided by horses and mules (Fox, 1966). These animals had to be fed from the land. With the adoption of the tractor, the land was freed to produce food for humans. A tractor feeds on oil. Not only land but labor also was freed by the tractor. One man plowing with a tractor could do the work of several men plowing with a mule. The net effect of mechanization is shown in table 6.

The displaced workers left the farms to go to the cities where they produced inputs for agriculture as well as the goods and services which constituted our gross national product (GNP). As we produced more goods, we consumed more and more of our stored-up energy. Farmers did not use this energy wantonly. Strong economic pressures forced them to mechanize.

Mechanical power had several advantages over animal power. First, it permitted one man to farm a larger area than he could manage with animal power. Given the low price of fuel, his expenses increased only marginally when he extended his acreage. Table 7 shows how the farmer could benefit by farming as much land as possible.

Second, animals eat even when they are not working. So if an animal is used only a couple of hundred hours per year, its cost-per-hour-worked will be exorbitant. However, the more the animal works, the lower its average cost per hour worked will be, and the more economical it becomes relative to the tractor (Jasney, 1935). Some farm animals were also used to pull wagons. As the truck and car replaced the wagon, the amount of work remaining for the plow horse was diminished and its average cost per hour worked increased substantially. The third advantage of the tractor relates to the Mill-Marshall theory about the division of labor on the farm.

The mechanization of labor created a necessity for more nonfarm inputs into agriculture. Many workers who were displaced by the new machines migrated to the city to produce machines and other nonfarm inputs for those who remained on the farm. In their new employment, these displaced farmworkers worked on monotonous assembly lines where the division of labor was more advanced than that on the farm. The four seasons no longer determined the pattern of their work; rather, they conformed to the more regular rhythms of the machine. So, in effect, much of the farmwork was transported from the farm to the city where it was performed like any other industrial process.

The efficiency of industrialization lowered the costs of these products to the point where they earned a substantial profit for the capitalists, who were able to sell them to the farmer cheaply enough to make them economical. For instance, Department of Agriculture estimates indicate that in 1947 five million persons worked in the industries that supplied farmers. By 1954 their numbers had increased to six million. Assuming a 40-hour week, these "workers spent 10 billion to 11 billion hours in producing goods and services purchased and used by farmers in 1947-1954. At the same time, work on the farms took 17 billion to 18 billion hours" (Hecht and McKibben, 1960). Industries that supply farmers still employ about six million workers, according to the 1967 Census of Manufacturers. However, by 1967 the number of workers employed directly in agriculture had fallen by 3.7 million from the 1954 level of 8.6 million. Thus, support from nonfarm workers is becoming a more important component of agriculture than the agricultural work itself (U.S. Department of Agriculture, 1971).

Table 8 gives some idea of the importance of nonfarm inputs to agriculture. The table lists the total farm production expenses between 1955 and 1969. These

TABLE 6—How mechanical power replaces human power

Year	Tractor power	All farmwork	Cost of operating and maintaining, farm capital
	Mil. hp.	*Mil. man-hrs*	*Mil. dol.*
1920	5	—	—
1950	93	15,137	5,640
1960	153	9,795	8,210
1970	203	6,522	11,755

Source: U.S. Department of Agriculture. Changes in Farm Production and Efficiency, A Summary Report, 1970. U.S. Dept. Agr. Statis Bull. No. 233, 1970. Agriculture Statistics 1972.

TABLE 7—Relationship between size of farm and cost of capital and other purchased inputs

Size of farm (acres)	Interest on operating capital (6% norm)	Volume discounts			Total difference from base cost per acre
		Fertilizers	Insecticides	Crop dusting & areal spraying	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Dol.*
80	6.88	0	0	0	0.56
160	6.52	4	0	0	-.25
320	6.47	4	5	0	-.53
640	6.47	4	5	12.5	-1.27
1,280	6.15	10	8.5	17.5	-3.96
3,200	5.90	10	[1]14*	25	-6.62

1/Denotes only one observation behind the data.

Source: Faris, J. E., and Armstrong, D. L. Economies Associated with Farm Size, Kern County Cash Crop Farms. Calif. Agr. Expt. Sta. Giannini Found. Res. Rpt. No. 269, pp. 73-96. 1963.

expenses are broken down into different categories. Notice that the cost of capital represents between a third and a fourth of all expenses. More than 10 percent of the total costs go to the Miscellaneous category, which includes pesticides. These miscellaneous expenditures, as well as capital, are used to replace labor. As a result, hired labor represents less than 10 percent of the total farm cost.

The important question is not how little labor we use on our farms, but whether we are using the proper mix of inputs. In the words of Solomon Fabricant (Hecht and McKibben, 1960):

> As a general rule . . . it is better not to limit productivity indexes that purport to measure change in efficiency to a comparison of output with a single resource. The broader the coverage of resources, generally, the better is the productivity measure. The best measure is one that compares output with the combined use of all resources.

We have reduced the amount of labor on the farm by replacing labor with machines. We have substituted fossil fuel energy for human energy.

Energy Use in Agriculture[4]

To show what high levels of energy consumption mean to agriculture, Fred Cottrell tried to compare the energy budgets of Japanese and American farming (Cottrell, 1955). He found comparable statistics for two rice farms, one in Japan and the other in Arkansas. Each had approximately the same yield per acre. In Japan, an acre could be cultivated and harvested with about 90 man-days of work, which is equivalent to 90 horsepower-hours (hp.-hr.). On the Arkansas farm, more than 1,000 hp.-hours of energy were used just to power the tractor and truck.

Moreover, the nonresidential consumption of electrical energy exceeded 600 hp.-hours. Cottrell did not even include the energy required to produce the tractors and equipment.

On the national level, our farmers use about 8 billion gallons of fuel to run their tractors (Fox, 1966). These 8 billion gallons represent about one thousand trillion B.T.U.'s of heat value or the equivalent of 40 gallons of gasoline for every American we feed. The average American consumes around 3,000 calories daily, which is equivalent to 12,000 B.t.u.'s, or an annual rate of consumption of about 4,380,000 B.t.u.'s. Since our population is about 200 million, we eat about 55 trillion B.t.u.'s, or about three-fourths as much energy as we burn in our tractors.

Electricity also contributes a great deal to farm production. The amount used by farmers accounts for about 2.5 percent of all electricity used (House Committee on Agriculture, 1971). In 1968 our electricity generating plants consumed the equivalent of a little more than 14,000 trillion B.t.u.'s (U.S. Department of Commerce, 1970). Thus, agriculture consumes the equivalent of 350 trillion B.t.u.'s of fuel, or an equivalent of almost 2 million B.t.u.'s for each inhabitant of the United States. The heat value of 2 million B.t.u.'s is approximately equal to that of 14 gallons of gasoline.

Our fertilizer industry also consumes enormous amounts of energy. Current technology requires about

[4]Perelman, Michael J. Farming With Petroleum. Environment 14(8):8-14. Copyright © 1972 by the Committee for Environmental Information.

TABLE 8–Expenses: Farm production expenses, United States, 1954-69[1]

Year	Feed, livestock, and seed[2] purchased	Ferti- lizer and lime	Capital equip- ment: Repairs operation[3], de- preciation, and other capital consumption[4]	Hired labor[5]	Taxes on farm prop- erty[6]	Interest on farm mort- gage debt[7]	Net Rent to non- farm land- lords	Miscel- laneous[8]	Total production expenses
	Mil. dol.	*Mil. dol.*	*Mil. dol.*	*Mu. dol.*	*Mil. dol.*	*Mil. dol*	*Mil. dol*	*Mil. dol.*	*Mil. dol.*
1955	5,995	1,185	7,300	2,615	1,141	402	1,057	2,204	21,889
1960	7,935	1,315	8,210	2,923	1,502	628	1,010	2,829	26,352
1965	9,299	1,754	9,055	2,849	1,943	1,077	1,328	3,628	30,933
1966	10,448	1,952	9,508	2,889	2,108	1,205	1,442	3,854	33,406
1967	10,541	2,124	10,241	2,878	2,275	1,343	1,305	4,068	34,775
1968	10,338	2,125	10,851	3,045	2,526	1,477	1,308	4,342	36,012
1969	11,505	2,013	11,500	3,192	2,753	1,602	1,303	4,576	38,444

1/ Includes Alaska and Hawaii, beginning 1960.
2/ Includes bulbs, plants, and trees.
3/ Includes expenditures for repairs and maintenance of farm buildings and other land improvements, petroleum fuel and oil, other motor vehicle operation, and repairs on other machinery.
4/ Estimated outlay necessary at current prices for the replacement of capital equipment that has been used up during the year.
5/ Includes cash wages, perquisites, and Social Security taxes paid by employers.
6/ Includes taxes levied against farm real estate and farm personal property.
7/ Interest charges payable during the calendar year on outstanding farm-mortgage debt.
8/ Includes interest on nonreal-estate debt, pesticides, ginning, electricity and telephone (business share), livestock marketing charges (excluding feed and transportation), containers, milk hauling, irrigation, grazing, binding materials, tolls for sirup, horses and mules, harness and saddlery, blacksmithing, and hardware, veterinary services and medicines, net insurance premiums (crop, fire, wind, and hail), and miscellaneous dairy, nursery, greenhouse, apiary, and other supplies.

Source: U.S. Department of Agriculture. Agricultural Statistics, 1970.

10^7 calories for each kilogram of nitrogen fertilizer we produce commercially (Delwiche, 1968). In 1969, U.S. farms consumed about 7.5 million tons of nitrogen fertilizer, which required about 2×10^{14} B.t.u.'s. This amount is equivalent in heat value of more than 1.5 billion gallons of gasoline, or about 8 gallons for each American we feed. But then, our nitrogen fertilizer makes up only one-fifth of our total commercial fertilizer supply (U.S. Department of Agriculture, Agr. Statistics, 1971). A. B. Makhijani estimates that the overall average energy use in the fertilizer industry is a little less than 2×10^7 B.t.u.'s per ton of fertilizer (Makhijani, 1972). Since our total 1969 fertilizer usage was about 40 million tons, Makhajani's figures represent a total of about 8×10^{14} B.t.u.'s or a heat equivalent of 30 gallons of gasoline for every American we feed.

The production of farm equipment also consumes much energy. The farm implement industry alone uses the heat value of about 4 gallons of gasoline for every American, not counting the energy used by the supporting industries that supply that industry (Makhijani and Lichtenberg, 1971).

Much of the energy used in the distribution and processing of food should be charged to the organization of agricultural production that has minimized production costs through regional specialization. This specialization requires that food be transported longer distances and also that much food be processed to avoid spoilage in the often circuitous road from farmer to consumer. In 1969, almost $5 billion was spent for transporting food by rail and intercity trucks.

The energy cost of the food processing sector is also significant. Makhijani estimates that this sector consumes about 10^{15} B.t.u.'s or an amount comparable to the consumption of energy by tractors (Makhijani, 1972).

Delwiche estimates that we use 1.5×10^9 calories of energy for each hectare (2.471 acres) of land we cultivate (Delwiche, 1968). We farm about 300 million acres of cropland (U.S. Department of Agriculture, Agr. Statistics, 1971). This much land (which does not include grazing land) would require the equivalent of about 3×10^{10} gallons of gasoline, or about 150 gallons of gasoline for each American we feed. His estimate does not take into account the energy required to produce the farm equipment, nor the energy used to store and distribute the food. Moreover, farmers purchase products containing 360 million pounds of rubber, about 7 percent of the total U.S. rubber production, and 6.5 million tons of steel in the form of trucks, farm machinery, and fences (House Committee on Agriculture, 1971). Farms consume about one-third as much steel as the automotive industry.

I don't mean to imply that agriculture is the main user of energy in our society. In 1970, the United States consumed about 64,000 trillion B.t.u.'s of energy (Cook, 1971). Thus, the average American consumes the equivalent of about 2,000 gallons of gasoline per year. For instance, a typical American consumes the energy equivalent of about 10 gallons of gasoline annually just to watch a black and white television set (Brune, 1972). By that standard, agriculture's consumption of 100 gallons of gasoline to feed one person does not seem extravagant. Besides, we use more than 20 percent of our acreage for exports that feed citizens of other nations. We also use some of our crops for industrial purposes (U.S. Department of Agriculture, Agr. Statistics, 1971).

The problem is that agriculture is supposed to be the *energy-producing* sector of the economy. The crops we harvest should capture solar energy and store it in a useful form so that we can use it to nourish our bodies or to perform some other service for us. Yet, the energy we capture is insignificant compared with the energy we burn in the process. Our agriculture has become a major consumer of our stores of energy, using more petroleum than any other single industry (U.S. Department of Agriculture, ERS, Aug. 1971). If we are facing an energy crisis, then we might measure efficiency in output of food per unit of energy instead of output of food per unit of labor. This new measure makes more sense because of the population explosion that causes many people to think of a redundancy of labor rather than a scarcity.

If we measure efficiency in the conservation of energy, then American agriculture comes out very poorly. Harris estimated that traditional Chinese wet-rice agriculture at its best could produce 53.5 B.t.u.'s of energy for each B.t.u. of human energy expended in farming it (Rappaport, 1967). But this energy came from people who burned rice in their bodies rather than from fossil fuel. If we are facing an energy crisis, then our present system of agriculture is clearly irrational. For each unit of energy the wet-rice farmer expends, he can get more than 50 units in return. For each unit of fossil fuel energy we expend (assuming we use no other energy than that consumed by our tractors, fertilizer industry, and electrical production for the farm), we get one-third unit in return. On the basis of these two ratios, Chinese wet-rice agriculture is more than 150 times as efficient as our own system. Moreover, if we include the energy expended by workers on the farm, as well as energy used to support other parts of the farm operation, American agriculture appears even more inefficient.

In 1969, we used more than 63,000 trillion B.t.u.'s of energy. About 10 percent of our total domestic demand for petroleum products goes to agriculture (Marshall, 1936). If this statistic were applicable for energy consumption as a whole, we could then estimate that agriculture consumes 6,300 trillion B.t.u.'s, or the equivalent of 200 gallons of gasoline per capita. On the basis of this estimate of the energy used in agriculture, Chinese wet-rice farming would be more than 300 times as efficient as our own. Of course, this ratio no more measures productivity than does the measure of output per farmworker.

U.S. wheat yields per acre are only slightly higher than those of Nepal and half as large as those of Denmark. Western European rye yields are about half again as high as U.S. yields and both Japan and Spain grow more rice per acre. Both the United Kingdom and New Zealand double our average oats yield and the Common Market yields of our own specialty, corn, are about 10 percent higher (U.S. Department of Agriculture, Agricultural Statistics, 1971). But we cannot conclude that one nation is more efficient than another just because it uses less of one input to grow a bushel of wheat. Bulgarians need about 20 percent less land than the U.S. farmer to grow a bushel of wheat while American farmers use less labor and more fuel in the process. To decide which is the most efficient is difficult. Figure 8 puts the value of American yields in an international perspective.

Thus, with either higher energy or higher agricultural prices, the large-scale, homogenous operation would lose much of its economic advantage over a more diverse, labor-intensive agriculture.

The Economics of Large-Scale Homogeneous Agriculture

Large-scale, homogeneous agriculture has other advantages over the small farm. Some of these advantages owe a great deal to tax accountants and attorneys. Through their expertise, nonfarm businesses and wealthy individuals can "farm." They can raise cattle or develop an orchard. These operations will not turn a profit until the cattle or the trees reach maturity, and so long as they do not produce any profit the owner can write off these expenses from his nonfarm income. When they are mature, he can sell out at a profit, and declare a capital gain so that he is taxed at a lower rate. The Government has long been aware of the danger to the small farmer of these tax loopholes. In 1963, then-Secretary of the

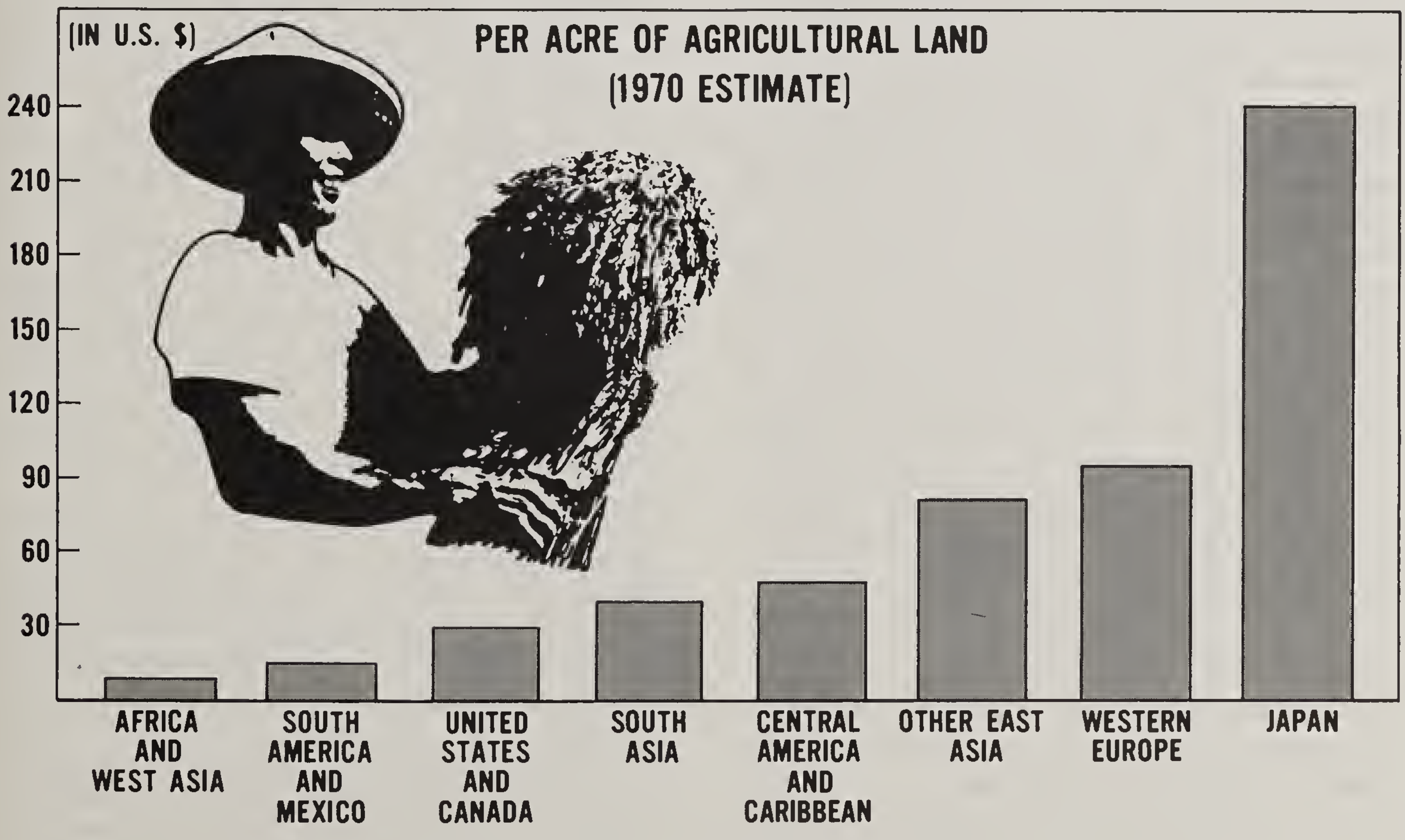

FIGURE 8.–Value of food production (Tendall, 1972).

Treasury, Douglas Dillon, told the House Ways and Means Committee that these so-called tax farmers "create unfair competition for farmers who may be competitors and who do not pay costs and expenses out of tax dollars but who must make an economic profit in order to carry on their farming activities" (House Ways and Means Committee, 1969).

Secondly, farm subsidies favor the largest corporations. Payments are roughly proportional to farm sales, so that the large farms naturally get more than the small ones. Moreover, "both price support and direct payment benefits of the farm commodity programs are more highly concentrated among the large farmers than is income itself" (Schultze, 1971).

One study by the Legislative Reference Service of the Library of Congress concluded that the large farm with over $40,000 in sales would have faced greater financial difficulties had price supports been discontinued. Costs on the average would have exceeded receipts for these large operations (Legislative Reference Service, 1965). In another study, Tweeten confirms these results (Tweeten, 1965).

A third advantage of the large farm is its ability to purchase inputs at a cheaper rate. Table 7 shows the relationship between farm size and the cost of capital and other inputs. Part of the profitability of the large farm rests upon this ability, indicating that profits may have little to do with efficiency.

One of the most crucial inputs for a farmer is credit and the small farmer has difficulty in getting it at reasonable rates. Industrialists who sell to the small farmer are aware of these difficulties. For example, the president of John Deere and Company, William A. Hewitt, had this to say about the availability of credit to the small farmer:

> To us credit is a sales tool. We provide it because we must (because banks do not) . . . . The paper we accept from our dealers carry higher rates than the banks charge for such paper and our rates are as low as any in the industry. Even so the amount of retail paper our company had on its hands last October 31 (1957), the end of our fiscal year, approximated one hundred million dollars, two hundred percent more than three years ago. *Surely the limited availability of credit from other lower cost sources must be a factor in the situation.*
>
> We do not attract this business by taking excessive risks. Our credit standards have been high. . . (and) our losses have been minor (Hewitt, 1958).

You might think that Mr. Hewitt was just complaining because he, too, like the banks, preferred not to lend money to the inefficient small farmer.

On the other hand, Don Paarlberg, USDA's current Director of Agricultural Economics, says, "We know from our studies in the Department that the rates of foreclosure and delinquency are greater on big farm loans, for the large scale farm units, than for smaller loans on family farms" (Paarlberg, 1971). That is, the "inefficient" small farmer makes a better risk than his larger more modern counterpart.

Why should large businesses go into farming if they are not more efficient than the small farmer? We have already touched on some of the reasons. To this list add two more: (1) A desire for the economic integration of their industries, and (2) speculation.

Let us begin with integration. An article in *Doanes' Agricultural Report* for January, 1968, entitled "Big Corporations Invest More In Agriculture," quotes Peter Grace, president of W. R. Grace, as follows:

> A study of insolvent farmers in California's San Joaquin Valley lends support to Paarlberg's statement. Twenty-eight percent of this sample of insolvent farmers had acreages of more than 2,000 acres and 76 percent had more than 5,000 acres. Only seven percent of the farms in the region had more than 2,000 acres and only 22 percent had more than 500 acres (Lane and Moore, 1972).

The article continues:

> Most firms supplying petroleum products and agricultural chemicals are being forced by the competition to offer credit (like John Deere and Co.). They would prefer not to do this, especially with today's high cost of money. . . .
>
> During the struggle for control of Kern County Land last summer, more than one fertilizer firm was interested in acquisition, from the standpoint of guaranteeing an outlet for a large amount of their products on the company's huge irrigated crop acreage.

In the end, Kern County Land Company was purchased by Tenneco Oil Company. Now Tenneco produces fertilizers for its almonds, which it harvests and packs. According to an article in *Western Fruit Grower* for October, 1969, Tenneco has 3,800 acres of grapes; 1,850 acres of almonds; 100 acres of citrus; and 900 acres of peaches and plums all on a very small fraction of its total land holdings. These are very lucrative specialty items which produce a valuable crop on just a few acres. Tenneco can supply its own petro-chemical products to run all aspects of its operation.

Tenneco provides us with a useful example of the principal reason large corporations enter the agricultural sweepstakes—speculation. Urbanization, farm subsidies, and the general growth of population all contribute to the rise in farm real estate values. Here is what an agricultural economist with the Federal Reserve Bank of Kansas had to say on the subject:

> Past rates of appreciation on farm land and rural estate have been impressive. Although there is not assurance of continued increase in land prices, acquisition of farm land remains an attractive inflationary hedge for firms with adequate liquidity. Because of other considerations such

as rapid transportation, urban sprawl, population growth, and expanding recreation needs, land may be acquiring a renewed investment appeal (Swakhamer, 1968).

Another agricultural economist put the answer more simply when he said, "Many people who invest in farmland . . . simply count on capital gains occurring; that is, a rise in the value of the land" (Reiss, 1968). Simon Askin, Tenneco's executive vice-president for agriculture and land development, agrees. He says that at Tenneco, "We consider land as an inventory, but we are all for growing things on it while we wait for price appreciation of development. Agriculture pays the taxes plus a little" (Askin, 1971).

The effect of favorable tax laws and cheap credit on large farms is that "high leverage (the ability to use borrowed money) and capital gains on the scale experienced over the past decade can convert a nominal rate of return on total investment of 1 or 2 percent into an effective rate of return on equity of 8 to 10 percent or higher" (Raup, 1970). Land speculation and the opportunity for vertical integration make large farming even more profitable. Stock market manipulations also play a role in making large-scale agriculture more attractive to nonfarm corporations. According to Walter Minger, a Bank of America vice-president:

> Most agri-business companies don't sell at near the P/E (price to earnings ratio) of the nonagricultural companies. In other words, a nonagricultural firm earning a hundred thousand dollars per year might be expected to sell for around two million dollars. On the other hand an agricultural firm earning the same amount might be expected to sell for seven hundred thousand dollars to one million dollars, or at a much more favorable P/E ratio. What this means is that the company acquiring the agri-business firm gets an immediate improvement in its share earnings (Fiola, 1969).

Thus, much of the profitability of large-scale farming has nothing to do with efficiency, but it does have a great deal to do with the viability of the family farm.

Given our unwillingness to put more money into the hands of the hungry, we have an oversupply of food. As a result, the market can be expected to signal that resources should be taken out of agriculture and channeled into other areas where they can be used to better advantage. But the subsidies, tax laws, and other forces give an opposite signal. They encourage corporations and wealthy individuals to devote more resources to agriculture, thus increasing the glut of food.

These counter signals are very strong. The subsidy program alone transfers from $9 to $10 billion from taxpayers and consumers into the hands of farmers (Schultz, 1971). The large liquid corporation finds this situation ideal. Only a small profit, if any, is earned on the growing of food, so few taxes have to be paid on this part of the operation. At the same time the land becomes much more valuable. No taxes (except property taxes) have to be paid on this increase in value until the land is sold, and then it will be taxed at the reduced capital gains rate.

The small farmer has different needs. Unless he can sell his harvest for a decent price, he cannot make a living. He needs his income today to pay for his current expenses. The rising land values do not help him much in his farming. He can take advantage of them only when he ceases to farm.

Many small farmers cannot hold on. Between 1950 and 1970, the number of farms in this country was almost halved (U.S. Department of Agriculture, Agr. Statistics, 1967 and 70). Moreover, the number of people employed on farms fell at a slightly faster rate. According to Rudolph A. Peterson, former president of the Bank of America:

> What is needed is a program which will enable the small and uneconomic farmer—the one who is unwilling or unable to bring his farm to the commercial level by expansion or merger—to take his land out of production with dignity(Agri-Finance, 1969).

This attitude can be traced back to Adam Smith's theory of the division of labor—the larger an enterprise becomes, the more advanced will be the division of labor. The same theory was brought out in support of regional specialization. This attitude is clearly shown in Smith's analysis of the discovery of America. For him, the importance of the discovery lay in the new markets it offered European manufacturers. As European factories expanded to meet the demand of these new markets, the division of labor would be furthered. In short, Smith believed that the division of labor would be most advanced when each nation specialized in a few products of which that nation was the sole supplier. His reasoning was taken one step further by David Ricardo, who argued that even if there were no advantages to be gained from the division of labor, world prosperity would be furthered when each nation specialized in the few items it could produce most efficiently.

Ricardo's reasoning was highly abstract and depended on severe assumptions, but it seemed reasonable at first glance. As one of his forerunners, Robert Torrens, explained, if because of English manufacturing skill "any portion of our labour and capital can, by working up cloth, obtain from Poland a thousand quarters of wheat, while it could raise on our own soil, only nine hundred, then, even on agricultural theory, we must increase our wealth by being, to this extent, a manufacturing rather than an agricultural people" (Torrens, 1815).

The logic of Ricardo and Torrens also applies to regions. When each region specializes in the items it can produce most efficiently, national prosperity is furthered. When we couple this argument with the theories about the division of labor, we have the classic rationale for regional monoculture.

Understandably, the economists who argued for national specialization usually came from manufacturing nations instead of countries who depended on agriculture. Economists from less advanced nations tended to argue more like Alexander Hamilton whose work anticipated Ricardo's. Underdeveloped nations, they maintained, were at a disadvantage compared with developed regions like Ricardo's England. Hamilton noted that "The labor of artificers being capable of greater subdivision and simplicity of operation than of cultivators" was "susceptible in a proportionately greater degree of improvement in its productive powers." Under such circumstances, "the substitution of foreign for domestic manufactures is a transfer to foreign nations of the advantages accruing from the employment of machinery." Moreover, Hamilton believed that the foreign trade between an agricultural and a manufacturing nation put the former at a considerable disadvantage. Thus, the aim of the United States ought not be to depend upon Europe for manufactures, but rather should have the aim of possessing "all essentials for national supply" (McKee, 1934).

The current economic power of the United States is proof of the validity of these arguments. How far would this country have developed had the economy been based on selling beaver hats and tobacco?

Hamilton's logic holds for regions as well. A region may be able to earn more money today by specializing in a few products, but in the long run it would be better off with a more diversified, self-sufficient economy.

A second objection to the division of labor comes from Adam Smith himself:

> In the progress of the division of labour, the employment of the far greater part of those who live by labour . . . comes to be confined to a few very simple operations, frequently to one or two. But the understandings of the greater part of men are necessarily formed by their ordinary employments. The man whose whole life is spent in performing a few simple operations, of which the effects are, perhaps always the same, or very nearly the same, has no occasion to exert his understanding, or to exercise his invention in finding out expedients for removing difficulties which never occur. He naturally loses, therefore, the habit of such exertion, and generally becomes as stupid and ignorant as it is possible for a human creature to become (Smith, Modern Library ed., 1937).

Similarly, when the people of a region specialize in a few products, their experience is narrowed. As a result, they cannot take full advantage of their human potential.

As we have shown, diversification is an investment in the future, and there are other advantages. Unfortunately, these benefits are often hidden. Consider a small mixed farm. The livestock provide manure and crop residues help maintain the livestock. Today, livestock is concentrated in urban areas. Manure piles rise, crop residues are burned, and the farmer falls back on chemical fertilizer. Each of these three separate operations pollute and the costs of this pollution are hidden. As production becomes isolated from consumption, food has to go through complex and expensive marketing channels. In part, this expense must be added to the cost of food production because as small regions diversify, simpler marketing organization suffices. Also, food must be treated with preservatives so that it is still edible by the time it reaches the consumer. All these costs are hidden when we look at spatial homogeneity from a narrow farm production standpoint.

The Nobel Prize-winning economist, Simon Kuznets, tried to quantify the effects stemming from the increasing complexity of modern life. The underlying cause of this complexity, as Kuznets sees it, is the shifting of labor from the farm to the city. Kuznets maintains that if a man from the city and his country cousin were to have identical standards of living, the city man would require more resources. Kuznets writes, "This higher input cost is reflected either in higher prices in the city than in the countryside for the same product (such as food) or in outlay on additional 'goods' required only because of the difference between rural and urban conditions of life (such as the need for more sanitation facilities in the cities because of greater population density)."

Kuznets calculated that these hidden costs amounted to more than 10 percent of our Gross National Product. Yet he ignored many "deprivations and discomforts" of urbanization "for which no economic price tag seems appropriate." He said "these may range from such obvious and distasteful consequences of modern economic growth as air and water pollution, to more subtle effects of urban civilization represented by the difficulties of maintaining privacy and of escaping from the vulgarities of mass media and from irrational and domestic violence" (Kuznets, 1971).

One who pays a great price for spatial homogeneity in agriculture is the migrant farmworker. In a very special sense, the use of migrant labor is a way of reducing monoculture FROM THE POINT OF VIEW OF THE FARMWORKER. For instance, in mixed farming the labor requirements are spread over a longer time because the peak labor period for one crop is the off season for another. Relatively little time is wasted in idleness. But economic considerations induce many farmers to move toward monoculture, which concentrates labor needs into short periods. The farmer can take advantage of the monocultural technologies because he doesn't have to bear the cost of the farmworker's idleness. Under monoculture, the worker is paid only when he works and for the rest of the year is unemployed. However, other growers producing other crops have labor needs that coincide with his slack periods. Since he cannot make enough from his seasonal work on one crop, he has no choice but to move on to the next. Thus, the migrant participates in polycultural farming except that the scale of farming that concerns him covers many farms and orchards owned by different concerns. So we might say that often the farmer can reap the economic benefits of monoculture by shifting the burden of nonmonocultural farming onto the migrant.

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